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A SIMPLE OPTICAL DEVICE FOR COMPLETELY ISOLATING OR CUTTING OUT ANY DESIRED PORTION OF THE DIFFRACTION SPECTRUM, AND SOME FURTHER NOTES ON ASTRONOMICAL SPECTROSCOPES.

By F. L. O. Wadsworth.

The overlapping spectra always produced by a diffraction spectroscope, while exceedingly useful and convenient in the determination of relative wave-lengths, are on the other hand very disadvantageous in photographic and bolometric investigation of the spectrum, particularly in the red and the infra-red regions. In order to isolate any desired portion of the spectrum of a given order, or to avoid the disturbing effect of the overlapping spectra in the classes of work just referred to, it is customary to either use absorbing screens, so chosen as to cut out as completely as possible those portions of the spectrum which are superposed on the part under examination; or to use what is known as the "lifting" prism, first proposed by Fraunhofer, and since used by Professors Young, Langley and others, by the action of which the different orders of spectra are displaced vertically by different amounts.

Of these two methods the first is the more simple and

direct, and since the absorbing media may be placed in front of the slit, the definition of the instrument is not affected by optical imperfections in the surfaces or material of the absorbing film or cell. The great practical disadvantage of the method is that there are no materials known which are perfectly transparent to some one portion of the spectrum and perfectly or even nearly opaque to other regions, and much time is frequently lost in trying to find solutions which will most nearly secure the selective absorption required. Professor Ames has published[1] a list of absorbing solutions which answer very well for particular regions of the visible spectrum, but none of these are well adapted to the extreme infra-red regions, and all of them diminish to a greater or less degree the intensity of those rays which they are intended to transmit, both by partial absorption and by reflection at the surfaces of the cell or film.

The second method of separating the spectra of different orders by the use of Fraunhofer's "lifting" prism placed between the grating and the eyepiece, completely accomplishes the object desired, *i. e.*, a complete separation of the different orders of spectra, and enables any portion of any order to be isolated or cut out at will by means of sliding screens placed just in front of the eyepiece or photographic plate. But this method has also obvious disadvantages due to the introduction of a prism in the spectroscope train. Owing to the position of this prism (refracting edge at right angles to the lines on the grating) the rigidity of the observing telescope is seriously affected; not only by its being brought into an unusual, and in many respects an inconvenient position, but also by the necessity for making it movable in a vertical plane in order to bring different portions of the spectrum into the center of the field.[2] This difficulty might be avoided by using the "direct vision fixed arm" prism train

[1] "The Concave Grating in Theory and Practice." *Phil. Mag.* **27**, 369.

[2] This last object may, it is true, be accomplished by rotating the prism alone on an axis parallel to its refracting edge, but only at the sacrifice of definition and brightness of the spectrum, since the diffracted rays then no longer pass through the prism at minimum deviation, except in one particular position.

PLATE XIV.

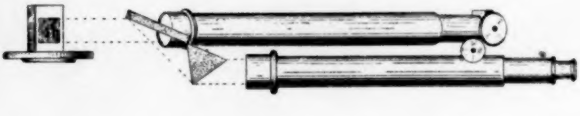

Fig. 1

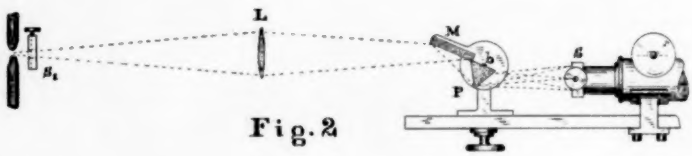

Fig. 2

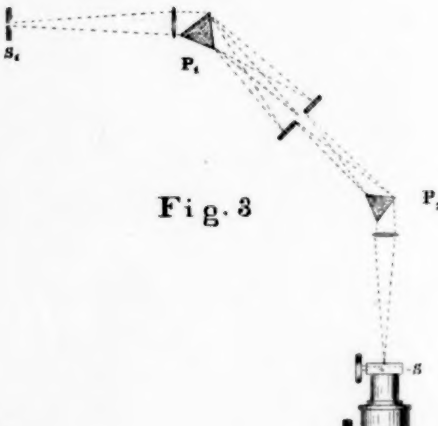

Fig. 3

described in a preceding paper.[1] The arrangement of parts then becomes the same as an ordinary plane grating spectroscope with fixed collimator and observing telescope, save that the latter is raised (or lowered) a distance equal to twice the distance of the axis of rotation of the prism from the horizontal plane passing through the axis of collimation (see Fig. 1, Plate XIV.). If the observing telescope were large enough even this small vertical displacement would be unnecessary, and exactly the same disposition of parts could be used with the prism or without.

A second disadvantage attending the use of the lifting prism which cannot be so easily and satisfactorily overcome, is that when it is used the spectra no longer cross the field at right angles to the spectrum lines, but are curved upward from the red end, the curvature becoming very great in the violet regions. This does not introduce any particular difficulty in the case of visual observations, but in photographic work it is very objectionable, especially when the spectrum is very narrow, because it renders the subsequent measurement and comparison of the lines on the dividing engine or comparator troublesome and more or less inaccurate.

In order to avoid injuring the definition the prism must of course be placed in front of the objective of the observing telescope. This is another disadvantage, for in order to completely utilize the full aperture of the grating we must have a prism with an aperture at least as large, and this for large instruments would not only be very expensive, but also very objectionable on account of the great absorption. Besides, the necessity for placing the prism, if used at all, in a parallel beam of light renders it quite impossible to use this arrangement with satisfactory results in the case of the concave grating.[2]

[1] "Fixed Arm Spectroscopes." *Phil. Mag.* **38**, 337, 1894.

[2] Three years ago at Professor Langley's request I made experiments on the use of a prism placed between a concave grating and its focal plane, the apparatus being arranged with special reference to the bolometric investigation of the grating spectrum.

The arrangement, which is referred to in the Smithsonian report for 1893, consisted

Recently, in reconsidering this problem with special reference to some proposed work with the concave grating, two new methods suggested themselves, both of which have been tried with success and found to be not only free from the objections to the methods just discussed, but to offer in addition certain advantages not possessed by either. In both a prism is used, but unlike Fraunhofer's arrangement this prism is placed outside the slit of the spectroscope, and can therefore be used equally well with either a plane or a concave grating, and is in both cases without effect on the definition of the instrument. In the first method the prism is placed with its refracting edge at right angles to the slit of the spectroscope and between the latter and the usual condensing lens, as in Fig. 2, and a second broad slit, s_1, whose length is parallel to the refracting edge of the prism (and therefore at right angles to the spectroscope slit itself), is placed just in front of the source.[1] The image of the first slit or opening, s_1, is thus drawn out into a spectrum whose length is parallel to the spectroscope slit, and every point of the latter is thus illuminated with light of a different wave-length. Hence the resulting spectral image of this slit will be a band inclined across the field just as in Fraunhofer's arrangement, the width of this band being determined by the width of the first slit, s_1, and the ratio of the conjugate foci of the condensing lens, L; and its inclination in the field being determined by the angular dispersion of the prism, P, and its distance from the spectroscope slit. Both the width and inclination of the diffraction spectrum may therefore be readily varied, the first by

of a large Rowland concave grating mounted in the usual manner with a direct vision prism mirror combination similar to that shown in Fig. 1, placed about two feet in front of the bolometer (which occupied the place of the usual observing eyepiece) and so mounted that as the bolometer strip moved down through the spectrum, the prism was, by means of a simple link and cam movement, automatically maintained in minimum deviation.

It was found that in spite of the most careful adjustment the definition was so much injured that the use of the prism in this way was impracticable except for the very roughest work.

[1] To avoid a change in the direction of the refracted rays we use in this case as before a direct vision prism mirror combination instead of the prism alone.

varying the width of s_1, the second by sliding the combination *PM* toward and from the slit *s*. In this case the diffraction spectrum may also be readily limited to any desired range of wave-lengths by limiting the vertical height of the spectroscope slit by stops, different portions of the spectrum being brought in succession into the field by rotating the prism and mirror, *PM*, on its horizontal axis, *b*. The distorting effect of the prism on the homocentric cone of rays from *L* is evidently without effect on the definition of the spectroscope itself, its only effect being to broaden and render indistinct the edges of the spectrum, an effect of the same nature as that produced by astigmatism in a concave grating.

This simple and efficient device has but one disadvantage: *i. e.*, the inclination of the spectra in the field of the observing telescope. The second method alluded to above overcomes also this disadvantage, although the arrangement of parts is not quite so simple as in the case just discussed.

If we turn the prism, *P*, and the first opening, s_1, 90° from the position which they occupy in Fig. 2, and allow the resulting prismatic spectrum to fall upon the spectroscope slit, *s*, we obtain what is in principle identical with the arrangement recently described by Tutton[1] as a new instrument for producing monochromatic light of any desired wave-length, and which had previously been used by Langley, Rubens, and others for the determination of wave-lengths in the prismatic spectrum. With such an arrangement the diffraction spectrum would be limited to a narrow band whose position could be changed by turning the prism on its axis, but whose breadth (in the direction of the length of the spectrum) could only extend over a few wavelengths, and could not therefore be used when it is desired to photograph or examine a considerable portion of the spectrum at once. But if, instead of allowing the spectrum formed by the first prism to fall on the spectroscope slit, we project it on a screen in which there is a rectangular opening whose length can be varied, and place behind this opening a lens and a sec-

[1] *Phil. Trans.* **185**, 913, 1895.

ond prism of the same refracting angle and dispersion as the first, in such position that the rays which pass through the opening will be reunited by the second prism and lens into a chromatic image of the first slit; and then project this chromatic image on the spectroscope slit, we shall obtain a diffraction spectrum which will be limited to those wave-lengths that have been allowed to pass through the opening in the first screen. This arrangement, which was the one first used, is shown in plan view in Fig. 3, which will be readily understood from the preceding description.

This arrangement soon proved, however, to be too bulky and difficult of adjustment for convenient use, and it was, moreover, difficult to obtain good chromatic images of s_1 at s, owing to slight differences between the two prisms P_1 and P_2. These difficulties were all overcome and the instrument got in very compact and convenient form by use of the Littrow principle of sending back the spectral rays on their own path by means of a double reflection prism R placed behind the screen D at the focal plane, with its hypothenuse surface perpendicular to the plane of refraction so that the chromatic image of s_1 fell just above or just below s_1 itself (see Fig. 4, Plate XV.). In this case the electric arc which serves as the source of light, instead of being placed directly against the first slit s, is on account of the proximity of this slit to the spectroscope, placed at some distance, and the image of the arc thrown on the slit s_1, by means of a condensing lens L'. The portion and the extent of the spectrum in the field can then both be readily varied, the first by moving the arm carrying the screen D and the reflecting prism R, and the second by varying the width of the opening in the screen at D.

This simple arrangement, which may perhaps be called an optical sifting screen, or sorting train, thus takes the place of an infinite number and variety of absorption screens or films. Since the lens L and prism P may be very small, they may always be made of materials which have a minimum absorption for the region under examination, quartz for the ultra-violet, white crown and flint glass for the visible, and rock salt or fluorite for the infra-red.

PLATE XV.

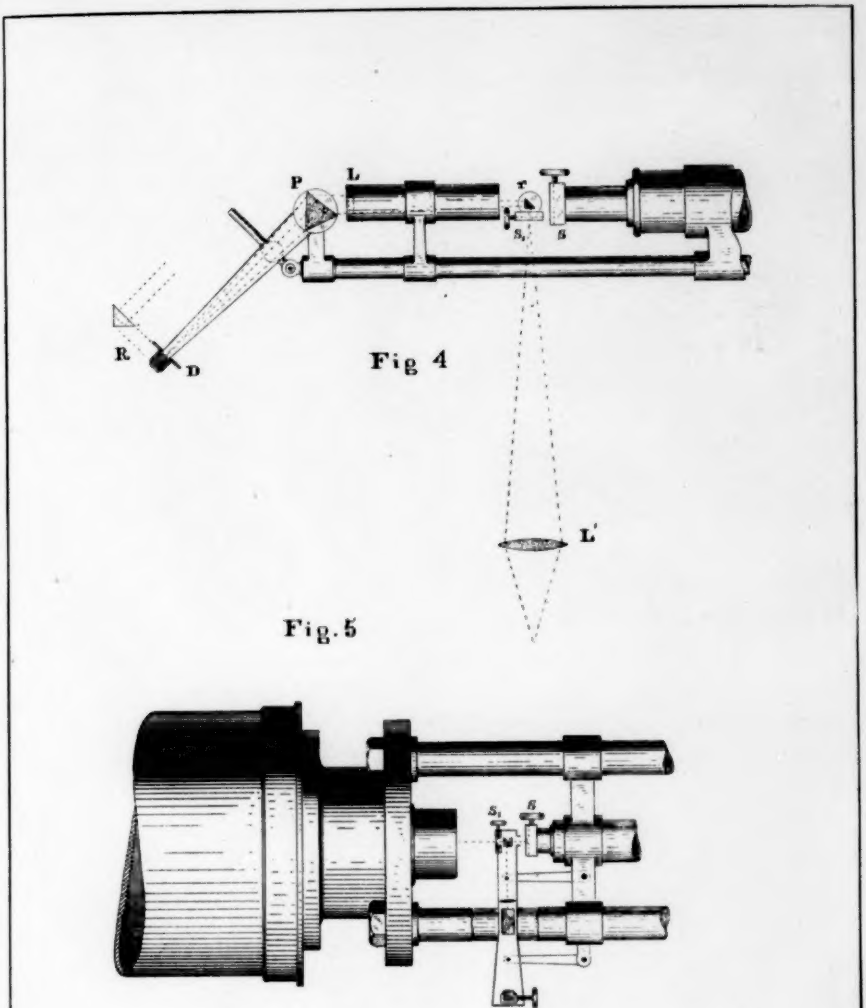

Fig 4

Fig.5

Fig.6

The slit s_1 is so mounted that it can be readily moved to one side, and the right angled prism r, which is placed just behind it, revolved through 90° so as to throw the image of the source directly upon the spectroscope slit. Among other things, this enables us to readily compare the brightness of the spectrum with and without the sifting train, and such comparisons show that by the use of the latter the brightness is diminished by not more than 20 to 30 per cent., or to about the same degree as by the use of absorbing screens. Even were the loss considerably greater, however, it would be more than offset by the greater convenience, range of control and perfect screening action of this sifting train.

The compactness and small size of the whole arrangement enables it to be readily mounted on the end of the collimating telescope or on an extension of the arm which carries it, as in Fig. 4. By slightly modifying the arrangement of parts the train may readily be introduced in front of the slit of an astronomical spectroscope, as shown in Fig. 5. In this case the axis of the train is at right angles to the axis of collimation, and a direct vision prism is used in place of the single prism in order both to make the arrangement more compact, and to secure good definition in the second slit image with the use of but one lens in the train. Instead of a direct vision prism we might also use a Christie half prism, since no great degree of resolving power is here required.

The tube containing the lens, prisms, etc., is so mounted that it may be readily moved to one side, allowing the image of the source to fall directly on the spectroscope slit s, which is then moved out until it occupies the place of s_1.

One property of this train, which makes it valuable for certain problems in the determination of wave-lengths, is the possibility of producing artificial bands or lines of any degree of blackness, in any part of the spectrum. To do this it is only necessary to stretch wires of the desired thickness across the screen D, which will cut off from the image which falls on the spectroscope slit all those radiations which fall upon the wires at

D, and produce consequently lines at the corresponding points in the diffraction spectrum. By using wires or strips of materials which are more or less transparent we can produce any desired degree of absorption or shading off of intensity in different parts of the spectrum, while by using metal wires which are opaque to radiations of all wave-lengths we can produce lines or bands which are absolutely black at least at the center.

One important application of these artificially produced lines in the diffraction spectrum is the determination of wave-lengths in the prismatic spectrum. The wire which crosses the prismatic spectrum may in this case be the vertical cross-wire of the eyepiece of the observing telescope, by means of which its angular position in the prismatic spectrum may be more easily and accurately determined than the position of a slit can be, and the position of the sharp absorption line in the grating spectrum can also be more easily and accurately fixed by means of the bolometer than in the usual arrangement, in which we have a more or less diffuse bright line on a dark background.

SPECTROSCOPIC NOTES.—*Relative Advantages of Large and Small Spectroscopes.*—In my article "General Considerations Respecting the Design of Astronomical Spectroscopes," which appeared in the first number of THE ASTROPHYSICAL JOURNAL,[1] certain general conclusions were reached in regard to the general design of the compound spectroscope (the objective spectroscope was not considered), which have been criticised by a number of astrophysicists, Professor Keeler among others. Professor Keeler's criticisms are contained in a note to the last March number of THE ASTROPHYSICAL JOURNAL, and as they are the most extensive and detailed of any that have been made, it is these that I will especially consider. I may first remark that my answer to these and others has been so long delayed for the reason that I first wished to finish the present series of papers dealing with the design of different forms of astronom-

[1] AP. *J.* January 1895, 1, 52.

ical spectroscopes in order that some of the points in the first paper might be more fully developed, and the conclusions there reached by theoretical considerations might be more completely confirmed or modified by further experimental work. But after another year's consideration and experiment, I do not feel called upon to modify in any essential degree the statements or conclusions of the first paper; but rather to emphasize more clearly some of them which do not seem to have been clearly understood (perhaps, because they were too vaguely or imperfectly stated) by my critics.

The logic and soundness of the assumption of constant resolution (or purity, which is directly proportional and at the limit equal to resolving power), rather than constant dispersion as a basis of comparison seems to have been generally admitted. The first point which is called in question is as to the relative advantages of large and small instruments of the same revolving power. Upon this point I think I was in some respects misunderstood by Professor Keeler. My contention was not that the small instrument was *universally superior* to the larger one, but that for *general* spectroscopic work it was equal to it in optical performance and superior to it in being lighter, more easily handled, and last but not least, cheaper, for very few astrophysicists can afford an instrument of 2 or even 1½-inch aperture.[1] The cost of construction diminishes very rapidly as the size of the instrument diminishes, for the cost of the Grubb[2] twelve-prism or the Young[3] ten-prism spectroscope of ⅞-inch aperture as listed by Grubb in his latest catalogue is only $250 for the former and $350 for the latter instrument, about one-tenth the cost of either the Lick or the Allegheny spectroscope. These instruments, however, are less complete in their arrangement than those designed by Professor Keeler, and are not provided with grating mountings, so that this great difference in cost is not entirely due to the difference

[1] The Lick spectroscope and the Allegheny spectroscope are each of about 1⅜ inch aperture and each cost between $3000 and $4000.

[2] *M. N.* **31**, 36. Schellen's *Spectralanalyse*, Vol. I.

[3] *Nat.* 3, 110.

in size. As regards rigidity, Professor Keeler admits that the advantages lie with the smaller instrument, and that this difficulty is less serious than the effect of a change of temperature during exposure, which change can certainly be more easily avoided in a small instrument by wrapping the whole in non-conducting coverings. The better optical definition of the smaller prisms due to greater homogeneity of the glass of the prism train is also admitted.

The somewhat greater loss of light by reflection in the case of the necessarily increased number of prisms with the smaller aperture is, however, unintentionally exaggerated. The increase in the loss of light in reducing the aperture one-half and using six instead of three prisms, is only about 9 per cent. (providing prisms of the most efficient refracting angle are used), instead of 25 per cent. as stated by Professor Keeler.[1]

"But," to quote Professor Keeler, "the most serious objection to the small aperture and high dispersion is perhaps the following: Since the linear extent of the spectrum cannot exceed a certain limit on account of the faintness of the light, it would be necessary to use a camera objective of very short focus. As compared with the other form of spectroscope having equal resolving power, the field would therefore be very small and only a short range of spectrum could be sharply photographed on a single plate." In the first place, this statement seems to imply a failure to perceive one important fact, which was indeed not clearly pointed out in my paper, but which follows directly from the expression for the dispersion:

$$D=\frac{d\theta}{d\lambda}=\frac{r}{a}.$$

This is the *angular* separation of two lines in the spectrum.[2] The linear separation of these two lines, or what may perhaps be termed the linear dispersion of the spectroscope, which

[1] See footnote *Ap. J.* 1, 250. For three prisms of refracting angle of 64°, index 1.6, the loss by reflection is 36 per cent. of the incident light; for six of the same kind 45 + per cent. See Table II., *Ap. J.* 1, 67.

[2] See also footnote (2), *Ap. J.* 1, 53.

we will denote by L, is found by multiplying D by f', or,

$$L = Df' = \frac{r}{a}f'.$$

But for similar instruments $\frac{f'}{a}$ = const. and therefore for r = const., L is also constant or *the linear dispersion is the same for all sizes of instrument.*

The brightness of the spectrum is likewise the same for all apertures, and hence the time of exposure for a given photographic plate will be the same.

The range of spectrum in a given angular width of field would decrease as the aperture decreases, and hence if we were limited to a certain angular width, less of the spectrum could be photographed at once. But from a geometrical point of view there is no reason why we should be so limited, since photographic objectives can be used which give a field of sufficient angular aperture to embrace the *whole* length of the visible and ultra-violet spectrum under any condition of dispersion that could practically arise.[1] The more important reasons why a large range of spectrum cannot be satisfactorily photographed on a single plate are, (1) the great difference in sensitiveness of the plate for different wave-lengths and, (2) the great change of focus (when lenses are used) a change which can only roughly be compensated for by inclining the plate to the axis of the observing telescope. But I agree with Professor Keeler in considering that the larger instrument is on the whole more satisfactory for some particular purposes, of which this is one. These cases were pointed out in a second paper[2] which dealt especially with the design of some large instruments and which had been written before Professor Keeler's article appeared. As I stated in that paper there is at least one case in which a large aperture

[1] With three prisms of white flint the angular dispersion from A (index 1.55) to H (index 1.6) is about 14°, and about twice this or 28° to the extreme ultra-violet. Considerably less than half of this, however, could be photographed on the same plate for physical reasons.

[2] *Ap. J.* **1**, 232, March 1895. See particularly p. 233. Also *Ap. J.* **2**, 264.

is absolutely essential, *i. e.*, the case in which a very high resolving power (100,000 or more units) is necessary.

Even granting that a grating of 40,000 lines per inch is practicable, this would require an aperture of 2½ inches to obtain the required resolving power in the first order. Professor Rowland has ruled satisfactory gratings as fine as 43,000 lines per inch,[1] but as a result of his long experience at Johns Hopkins he now recommends the use of gratings of from 10,000 to 15,000 lines per inch. With these gratings of course still larger apertures are necessary, unless spectra of higher orders than the first are used. So far in the comparison of grating spectroscopes of different apertures we have supposed that the same order of spectrum is used in different instruments, and if the brightness of the different spectra followed any uniform law, this would evidently be the true basis of comparison. But the fact that gratings may be obtained (though only by trial unfortunately) which have almost any desired anomaly, *i. e.*, are bright in almost any spectrum, gives the coarse-ruled grating a great advantage over the finer ruled gratings as respects its resolving power for a certain aperture.

Indeed, if we assume that the grating is placed in some particular position with respect to the axis of the spectroscope, *i. e.*, if the angles of incidence and diffraction are made constant, it is easy to show that the resolving power of the grating for light of any particular wave-length is *independent of the grating space* and depends only on the actual linear aperture of the grating.

For we have,—(using same notation as in previous article)

$$mn\lambda = a''(\sin\theta + \sin i)$$

and if θ, i, and λ are constant we have

$$mn = r = a'' \text{ const.} \ldots .$$

which shows, as stated, that the resolving power of the grating depends only on the linear aperture. It would not matter whether the grating were ruled with 10 or 1000 lines to the mm.,

[1] "Preliminary notice of results accomplished in the manufacture and theory of gratings for optical purposes." *Phil. Mag.* **13**, 469.

provided only all orders of spectra were equally bright, or provided the light could be concentrated in the spectra which were in the field for the particular position chosen. The impracticability of doing this in the very high orders of spectra, unfortunately, make it impossible to avail ourselves of the obvious advantages which coarsely ruled gratings possess in the way of cheapness, wide range of resolving power and dispersion, and possible great size.[1]

The maximum resolving power of the grating will be reached when $i = \theta = 90°$. For this case we have

$$r_{\text{max.}} = 2\frac{a''}{\lambda},$$

which shows that the maximum resolving power of a grating is just twice the resolving power of a telescope of the same aperture. For a 10^{cm} aperture this corresponds to a maximum resolution of 400,000 units, or just about sufficient to separate the two components of the green Cd line which was recently found by Michelson[2] to be double. An aperture of 25^{cm} would have a maximum resolving power of 1,000,000 and would, if optically perfect, separate the fine components of the mercury and thallium lines, the closest of which are not more than $\frac{1}{800}$ the distance between the D lines.[2]

Of course the maximum resolving power could never be practically attained, both on account of the extreme faintness of the light at angles of incidence near 90° and because of optical imperfections of the grating itself. Still larger apertures than 25^{cm} even are therefore essential if we are desirous either of separating the spectrum lines into their components or of attaining the highest degree of accuracy in fixing their position. In these respects the grating can never hope to equal in delicacy the spectroscopic interferometer or "wave comparer," but the latter

[1] Since writing the above I have discovered that this relation has previously been pointed out and its consequences brieflly discussed by Rowland in a recent article (*A. and A.* Feb. 1893, p. 133). I may remark, however, that this relation does not seem to be generally recognized, inasmuch as one often meets with the statement that the resolving power of a grating depends upon the number of lines ruled upon it.

[2] See "Application of Interference Methods to Spectroscopic Methods." A. A. Michelson. *Phil. Mag.* September 1892.

unfortunately is applicable only to the more intense of the bright lines of the spectrum and cannot be used for the examination of absorption lines.

The recent discoveries of Messrs. Jewell, Humphreys and Mohler, whose papers were published in the last number of this JOURNAL makes the individual examination and measurement of the lines of celestial spectra a problem of the greatest interest and importance, and one which demands more powerful instruments than any that have yet been constructed. It is to be hoped that the difficulties which have heretofore prevented the successful production of gratings larger than 6-inch aperture may soon be overcome, and that in the near future gratings of 10-inch, 12-inch, or even 15-inch and 18-inch aperture may be constructed to go with the great refractors and reflectors now in use. Since gratings of 4-inch aperture have been successfully used with telescopes of only 12-inch aperture, it would seem that for the Lick and Yerkes telescopes we ought not to be satisfied with less than a 12-inch or 15-inch grating.

The last point of disagreement between Professor Keeler and myself is in regard to the general design of the compound spectroscope. It seems to me that in every respect the reflector must be considered superior to the refractor for the purpose of celestial, especially stellar, spectroscopy. The absence of chromatic aberration is not by any means the only or the chief advantage; the freedom from absorption is perhaps quite as or even more important, particularly when work in the ultra-violet or infra-red is in question; while the large field obtainable in spectrum work (all parts of the field being in focus at once); the coincidence of the visual and the photographic foci; the much greater aperture possible, combined with very short focal lengths and great compactness; and finally the far less cost of the reflector as compared with the refractor; these are all advantages of almost equal importance. The great disadvantage of the reflector, its sensitiveness to flexure and consequent poor definition, is here of comparatively little importance, for it acts merely as a condenser,

concentrating the light of the star on the slit. Moreover, there is but little doubt but what the definition of very large reflectors can be very considerably improved over what has generally been obtained in the past, by proper proportioning of parts and proper mountings.

This is a question which will soon be discussed by Professor Hale in another paper and will not therefore be taken up here. As already stated, the question of good definition is not so important in the case of the compound spectroscope as the question of size. Hence it may be quite possible to use for this purpose mirrors of cast iron or cast steel instead of glass, the surface of the cast metal being first worked to the proper curvature, and then covered with a thick coat of nickel electrolytically deposited to receive the final working and polishing.

The principal objection which Professor Keeler urged against the use of reflectors, particularly short focus reflectors, was that they necessarily implied the use of mirrors instead of lenses in the spectroscope train, a substitution which Professor Keeler considers "highly objectionable, as according to all experience a mirror cannot be depended upon when stability is required." My reasons for a contrary view, based upon both my own experience and that of others, are given at some length in the same article to which reference has already been made.[1] The importance of this question, however, will certainly justify my referring to this matter again and adducing some further arguments and recent experiments in support of my position.

In the first place attention may be called (1) to the fact that many modern meridian instruments (in which the greatest stability and permanence of adjustment are required) are of the broken-tube form, a reflecting prism or mirror being inserted between the objective and eyepiece; (2) that the plane and concave gratings which are now universally used in the most accurate measurements of wave-length are both essentially reflecting instruments; (3) and most striking of all that the various forms of refractometer and interferometer, with which such marvelously

[1] See particularly pp. 242–3, *Ap. J.* March 1895.

accurate measurements of various physical quantities have been made by Professors Michelson, Morley and others, are combinations of from three to seventeen reflecting surfaces, from some of which the ray is reflected twice, and any displacement of which during the course of the observations would introduce errors whose magnitude in comparison with the quantity measured would be enormously greater than any corresponding error due to the displacement of a mirror in an ordinary spectroscope train. Thus, for example, in the instrument used by Michelson and Morley in their experiments on the relative motion of the Earth and the luminiferous ether,[1] there were seventeen reflecting surfaces, from fifteen of which the light is reflected twice. The accuracy of measurement attained in this case corresponded to a change of position of one of the interference fringes by about $\frac{1}{100}$ of its own width, or a change in distance of about $0^{mm}.000003$. Since the aperture of the mirrors was about 50^{mm}, this change would correspond to an angular movement of any one of the seventeen mirrors (supposing the mirror to turn about one edge and the displacement of the fringe to be measured at the center of the field) of less than $\frac{1}{80}''$. Of course the displacements of the different mirrors might have happened to be compensatory, but the arrangement was such that they were just as likely to be all in the same direction, and in the latter case no one of them could have been displaced by as much as $0''.002$, a quantity far beyond the range of the most powerful astronomical telescope. It must be remembered also that in the case of these observations the whole optical system was in continuous rotation and that the distance between the successive mirrors was nearly two meters. The total time of observation extended over an hour or more, but the interval between two successive observations, during which accidental displacements might occur, was less than one-half a minute, so that these measurements, although showing conclusively the stability of the combination for short intervals, does not demonstrate it for long ones. But in some experiments which I have made with the recent forms

[1] *Am. Jour. Sci.* **34**, 333.

of the instrument known as the wave comparer and the astronomical interferometer (the first of which has four, the latter six reflectors), these instruments have been left (exposed in the laboratory, which in one case was just above the instrument shop containing the engine, dynamo and a number of machine tools in constant operation) for from twenty-four to forty-eight hours without having changed in adjustment by an amount greater than at most 5″ of arc during the whole interval.[1] This shows, I think, conclusively that when mirrors are properly mounted and protected from such temperature changes as would seriously affect refracting instruments also, they may be depended upon to remain in practically perfect adjustment during the most prolonged exposures. For this reason I have thought it unnecessary in any of the instruments which I have recently described to make use of the double reflection prisms or mirror combinations shown in Fig. 6, in which the displacement of the prism is without effect on the angle of deviation of the doubly reflected ray.

If very great temperature changes or very serious vibrations were to be feared it might be advisable to make use of one of these forms, or of any other in which two successive reflecting surfaces are rigidly connected together.

I feel confident that the advantages of reflectors over refractors in spectroscopic work are so many and so great, and their disadvantages so few and so easily overcome by proper methods, that they will be used in the future far more than they have been in the past.

Most Advantageous Linear Dispersion for a given Aperture.— There is a point which has not yet been considered of special interest in the design of astronomical spectroscopes, particularly if they are to be used as spectrographs. This is as to the best linear dispersion to be given to any particular instrument. The angular dispersion for a given aperture and a given resolving power is a constant which is the same for both the prismatic and the diffraction spectroscope, and which is, in the one

[1] The fringes disappear completely when the mirrors alter their adjustment as much as 1′ in the case of the first instrument and as much as 10″ in the case of the second.

case, perfectly independent of the number or the refracting angle of the prisms, and in the other, perfectly independent of the fineness of the ruling or the order of the spectrum. As already shown, however, there is a definite relation between these last two sets of quantities, and *the aperture remaining constant*, a given dispersion (or given resolution, since the two quantities are, under the condition of constant aperture, exactly proportional), may be obtained in two ways: in the case of the prisms by use of a small number of prisms of large refracting angle, or by a large number of smaller refracting angles; in the case of the grating by the exactly analogous methods of employing a low order of a grating of a large number of lines per inch, or a high order of a grating of a smaller number of lines per inch. The relative advantages of these two methods in the case of prisms have been discussed in a preceding paper,[1] where it was shown that on the ground of compactness, simplicity and lightness it was preferable to use prisms of much larger refracting angle than at present employed—in some cases as high as 80°—the increased loss of light being very small, and in some cases even less than with the larger number of more acute angled prisms. The corresponding case for the grating is considered in an earlier part of this same paper (see pp. 180, 181).

The linear dispersion of the instrument, however, is variable with the length of the observing telescope, and the question is, how long is it desirable to make this; in other words, what should be the value of the ratio $\frac{a'}{f'}$. In observations with any optical instrument there are three properties with which we are concerned, viz., resolution, definition and accuracy. With regard to the first two there are two cases which must be considered: (1) that of visual observations, in which these properties are dependent upon physiological conditions; (2) that of mechanical registration by photography, bolometry, etc. In the first case, if the objective of the instrument were perfect, the

[1] "A New Multiple Transmission Prism of Great Resolving Power." *Ap. J.* **2**, 264, November 1895, see particularly pp. 271,272.

performance would be independent of the ratio of focal length to aperture. Practically, however, the effect of aberration, which increases as the fourth power of the semi-angular aperture,[1] prevents the use of angular apertures greater than $\frac{1}{14}$ to $\frac{1}{18}$ in the case of single lenses of glass of from 25^{cm} to 1^{m} focal length, or greater than $\frac{1}{14}$ to $\frac{1}{10}$ for spherical mirrors of the same focal length. In compound lenses or parabolic mirrors this ratio may be increased, but not much beyond $\frac{1}{8}$ to $\frac{1}{7}$ in the case of lenses, or $\frac{1}{5}$ to $\frac{1}{4}$ in the case of mirrors. The longer focal lengths are also somewhat preferable, because they allow a given degree of magnification to be obtained with a lower power of eyepiece. For purely visual observations (not measurement) there is, however, no need of making the focal length more than ten times the aperture. In photographic or bolometric work the case is different, because of the finite size of the silver grains in one instance and of the bolometer strip in the other. It has been shown by Rayleigh[2] that two lines are just "resolvable" visually when the angular distance between them is such that the central maximum in the diffraction image of one coincides in position with the first minimum of the other. In this case the diffraction pattern due to the two lines (supposed to be of equal intensity) is that shown in Fig. 7. The intensity at the points *a* and *b*, the positions of the geometrical images, is about 1.23 times the intensity at *c*, the point midway between them. In order that these two lines may be distinguished in the photograph it is evident that the differences in density in the photographic image must be nearly as great as differences in intensity in the original diffraction pattern.[3] Hence the points *a*, *c*, *b*, Fig. 7, must fall on *separate* silver grains in the photographic film, and these silver grains must be sufficiently far apart to

[1] "Investigations in Optics," Lord Rayleigh, *Phil. Mag.* **8**, 411, November 1879. See also "Wave Motion," *Enc. Brit.*, **34**, 431.

[2] "Investigations in Optics," *Phil. Mag.* **8**, 261, October 1879. See also "Wave Theory," *Enc. Brit.*

[3] Not quite as great, because if the negative is examined by transmitted light the diffraction in the observing microscope or eyepiece will cause the darker central strips to appear narrower and sharper than they would otherwise, just as in the use of a trans-

avoid the effects of photographic irradiation. A direct examination under a high power microscope of some solar negatives made on Seed 26 plates showed that in dense parts of the negative the reduced silver grains were practically in contact and on portions of average density the grains acted upon were separated by about their own diameter. Hence to eliminate the effect of irradiation in the one case and to obtain a normal action in the other, the grains a' b' c' should be separated by about their own

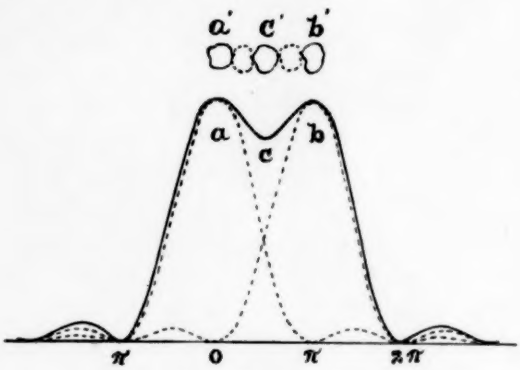

Fig 7

diameter, *i. e.*, the distance from the center of a' to the center of b' should be equal to about four diameters of a' or b'. This enables us at once to determine the linear dispersion necessary to obtain the required resolution on a photographic plate. If we call e the mean diameter of the silver grains we must have

$$ab = 4e.$$

But, from the wave theory,

$$ab = \frac{m\lambda}{a'} f',$$

parent galvanometer scale (black lines on a bright ground) lines may be separated whose angular distance apart is less than the resolving power of the galvanometer mirror. This same effect has also been observed and explained by Boys. "On the Newtonian Constant of Gravitation," C. V. Boys, *Phil. Trans.* 1895, A., **186**, 1 (see p. 31).

where m is a const., which is equal to unity for a rectangular aperture of width a', and equal to about $\frac{5}{4}$ for a circular aperture of the same width,

$$\therefore \quad \frac{a'}{f'} \equiv 0.3 \frac{\lambda}{\epsilon}.$$

If we take as the mean diameter of the silver grains $0.^{\text{in}}0002$[1] the ratio $\frac{a'}{f'}$ becomes 0.03, or the focal length of the observing telescope ought to be about 35 times the aperture in order to obtain details as fine as can be recognized by the eye directly. There is, on the other hand, no great gain in photographic definition by increasing the focal length much beyond this point, certainly not in making it several hundred times the aperture as has been frequently proposed.

In the case of the bolometer the question is rendered more complicated by the fact that the resolving or discriminating power of the bolometer depends not only on the relative but also on the absolute differences in the spectrum. The consideration of this question in detail will soon be taken up. It is however evident that in general the distance between the geometrical images, a, b, must be at least equal to the width of the bolometer strip in order that the bolometer may recognize them as separate lines. Hence if we call the linear width of the bolometer δ, we have

$$\frac{a'}{f'} = 1.22 \frac{\lambda}{\delta}.$$

Hence for a bolometer $0^{\text{mm}}.1$ wide, used in the region of wave-length $\lambda = 10{,}000$, the ratio of a' to f' should be about $\frac{1}{80}$.

For the purpose of accuracy it is also desirable to increase the focal length in order to magnify the width of the diffraction fringes with respect to the micrometer cross-wires. As is well known, the accuracy with which a cross-wire may be set on a fine line depends directly on the width of the central bright fringe of the image with respect to the cross-wire itself. The accuracy increases, other things being equal, until the width of

[1] *Publications of the Lick Observatory*, 3.

the fringe is from 75 to 100 times the width of the cross-wire, after which it begins to fall off.[1] In an ordinary telescope it is not possible to magnify to this degree because of the decrease in the brightness of the image, but it is always advantageous to carry the magnification as far as possible, increasing the brightness when it can be done by placing a cylindrical lens in the eyepiece to contract the width of the spectrum as far as possible. To secure a fair degree of accuracy in setting, the central fringe should be at least ten times as broad as the cross-wire, and since the finest cross-wires have a diameter of at least $0^{mm}.003$ and the width of the central fringe for a circular aperture is

$$w = 2.44 \frac{\lambda}{a'} f',$$

we have for the angular aperture under these conditions:

$$\frac{a'}{f'} = \frac{2.44\lambda}{.03} \equiv \frac{1}{25}.$$

Whence we conclude that both for purposes of photographic definition and accuracy of direct micrometric measurement, the focal length of the observing telescope should be at least thirty to forty times its aperture, or from two to three times its usual length. If the source is too faint to permit of so great a magnification, then the resolving power of the spectroscope should be decreased until the use of this ratio becomes possible.

This gives us a criterion for determining the maximum resolving power which can be used with advantage for a source of given brightness.

The necessity for this large ratio betweeen focal length and aperture is another strong argument for keeping the latter as small as possible. It will be noted also that it is of no advantage either for the purpose of photographic resolution or accuracy of measurement to simply increase the distance between the lines without increasing their breadth, and that therefore the use of a reversion prism or reversion objective is of little practical value in absolute spectrometric work, although ofttimes convenient in

[1] "Measurement by Light Waves." A. A. Michelson, *Amer. Jour. Sci.* **39**, 115.

determining relative positions of different lines in the same spectrum.

Various Forms of Prisms.—In all of the preceding discussions I have considered only simple prisms. None of the generality is lost, however, by such a discussion, because any compound prism (used in the position of minimum deviation), is simply equivalent to a train of simple prisms of some particular refracting angle, which in general will be more efficient in light transmitting power and in optical definition than the single compound prism. Indeed about the only advantage of the latter is in the reduction of the number of independent pieces in the spectroscope train, a reduction which is hardly worth the price paid. The half-prism is also far inferior to the train of simple prisms because of the greatly increased thickness of glass traversed for a given resolving power, and although half-prisms usually give very bright spectra, very elementary considerations will show that this is secured only at a great sacrifice of purity and resolving power. The superiority of trains of simple prisms was pointed out long ago by Lord Rayleigh,[1] but his excellent discussion of this and other points seems to have received less attention than it deserves at the hands of spectroscopists. His series of papers in the *Phil. Mag.* (1879–80) and his articles on Optics and the Wave Theory in the last edition of the *Enc. Brit.* which have been so frequently referred to, must form for many years to come the basis of all theoretical discussions of the design not only of spectroscopes but of optical apparatus in general.

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January 1896.

[1] "Investigations in Optics," Sec. 8. The Design of Spectroscopes, *Phil. Mag.* **9**, 49, January 1880.

ON TWO SOLAR PROTUBERANCES, OBSERVED JULY 15 AND SEPT. 30, 1895.

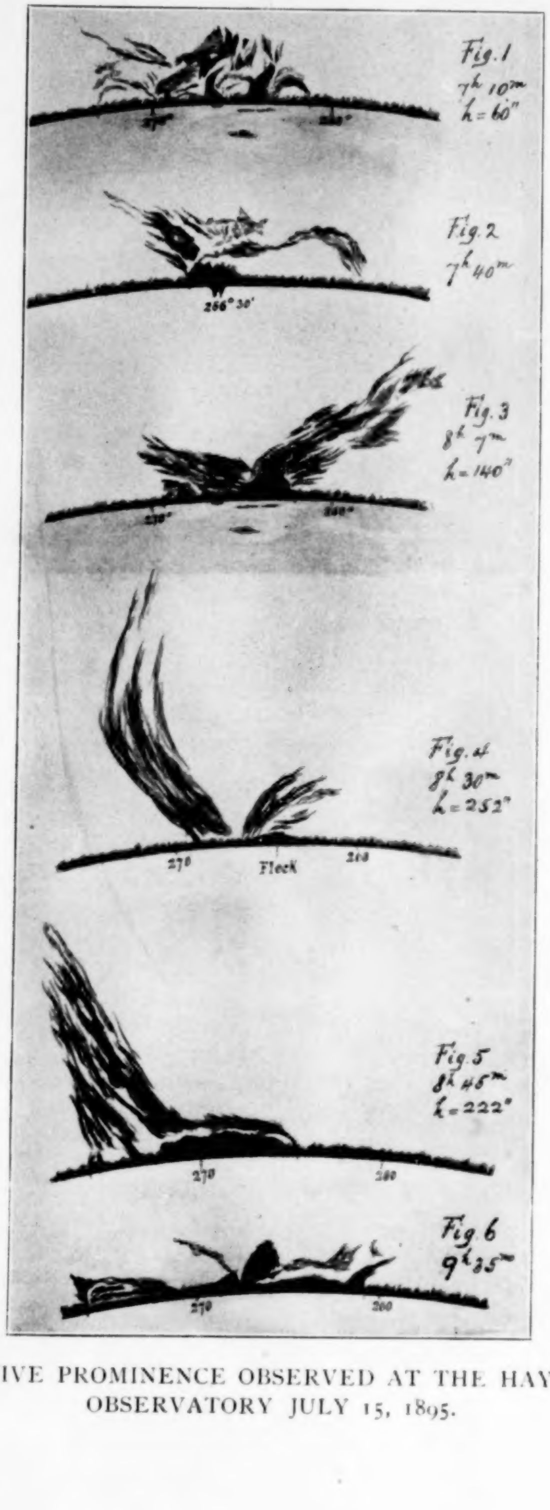
By J. FÉNYI.

THE first of these phenomena was remarkable on account of the enormous velocity in the line of sight, reaching 858^{km} per second, which was observed at that time; the second on account of the vast height to which the protuberance rose, through the great velocity of its ascent. A height of $11' \, 28''$ was attained, with a mean velocity of 448^{km} per second.

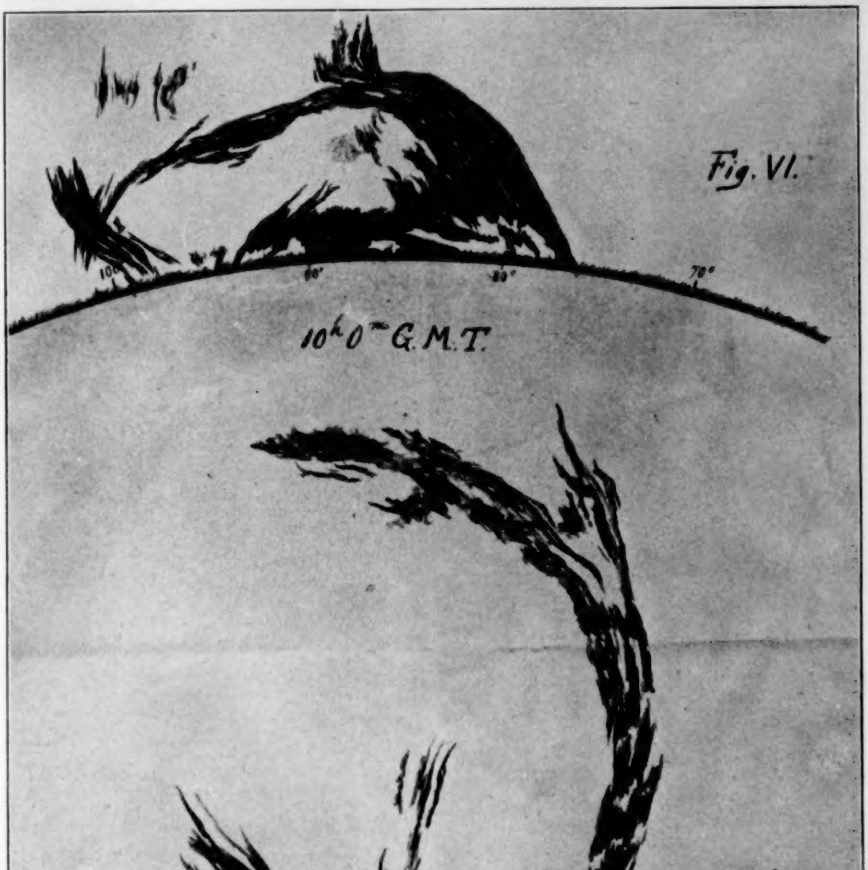
On the fifteenth of July, at $7^h \, 10^m$ A.M., Greenwich Mean Time,[1] a very delicately formed prominence of $60''$ height stood in position angle $272° \, 34'—261° \, 38'$, corresponding to a heliographic latitude of $-1° \, 14'$ to $-12° \, 10'$ on the western limb of the Sun. It was precisely on the place where a considerable group of Sun-spots was passing out of sight (Plate XVI, Fig. 1). Along the entire base was visible the line $\lambda \, 6677$, which is characteristic of regions of eruption. The most active region was at 266°, where, at $7^h \, 24^m$, the $H\alpha$ line (or, according to the older notation, the C line) appeared greatly widened, indicating a motion of 138^{km}; at the same place a small protuberance could be seen, even in the line $\lambda \, 6677$. At $7^h \, 44^m$, a very large motion in the line of sight was betrayed, at a small distance above the chromosphere, which, by measurement with the filar micrometer, amounted to 324^{km} recession per second; at the same time two cone-shaped projections appeared on the red side of the $H\alpha$ line, which could not be seen in $\lambda \, 6677$. While the displacements above mentioned were being measured, the form of the protuberance changed with extraordinary rapidity; Fig. 2 was drawn at $7^h \, 40^m$. Still more rapid, however, were the changes in the forms produced by displacement, which, when the affected

[1] Times are given in mean time of Greenwich, but according to the civil method of reckoning from midnight; the moment here referred to is therefore in astronomical reckoning July 14, $19^h \, 10^m$ G. M. T.

PLATE XVI.



ERUPTIVE PROMINENCE OBSERVED AT THE HAYNALD OBSERVATORY JULY 15, 1895.



ERUPTIVE PROMINENCE OBSERVED AT THE HAYNALD OBSERVATORY SEPT. 30, 1895.

regions were caused to pass slowly over the the slit, appeared like tongues of flame flaring in the wind. Measurement of the displacements, to which my attention was now turned, gave the following velocities; they do not refer to precisely the same point, but are maximum values for this part of the protuberance.

A little before 7^h 50^m, motion from us 483^{km}, toward us 303^{km} at the same place; at 7^h 50^m, motion from us 526^{km}; the displaced light was entirely separated from $H\alpha$. At 7^h 55^m, motion from us 771^{km}, and at the same time a motion toward us, two measures of which, uncorrected for slit-width, gave 512^{km}. The same displacement was visible in the line λ 6677. The greatest velocity was $858^{km}.8$ toward the Earth. The amount of the displacement at any moment was determined by measuring the distance from other spectral lines.

In the mean time the protuberance had assumed the form shown in Fig. 3. In the center of the eruption a protuberance $27''$ high could now be seen in λ 6677. The protuberance was sketched again; it had the form shown in Fig. 4, with a height of $252''$ at 8^h 30^m. Three transits over the slit gave accordant values, from which it appears that the protuberance did not rise very rapidly, although it is also possible that dissolution at the summit kept equal pace with the ascent. The relative positions of the Sun-spots which are shown in the figure near the limb were observed directly in the spectroscope; the nearest spot was only $2''$ from the limb, exactly on the place $266°$ $30'$ where the greatest eruptive activity had been displayed in the beginning. Fig. 5 was drawn at 8^h 48^m; measurement of the height gave $222''$, with indications of ascent. This form remained nearly the same during the last quarter of an hour of observation.

I now proceeded with an examination of the rest of the limb, and on completing it, at 9^h 35^m, found only a small protuberance on the first spot, with a height of perhaps $30''$. At 10^h 45^m the appearance was the same, and at 1^h 30^m P.M. the eruption had come to an end, after an existence of from 8^h 56^m to 9^h 35^m.

The group of spots over which these phenomena were displayed had begun to develop rapidly a few days before.

The second protuberance, observed on September 30, was noticed at 10^h A.M. in the first stages of development. On the east limb of the Sun, in position angle $76° 26'$ to $98° 52'$, or heliographic latitude $+17° 16'$ to $+39° 42'$, I found a prominence of extraordinary brightness, the height of which might then have been only about $60''$. It is shown in Plate XVII, Fig. VI, according to a very carefully executed drawing. The definition was remarkably good, but on account of the rapid changes in the prominence, the drawing represents an average state of the observed form. Turning then to measurements of its height, I obtained $240''$ at $10^h 11^m$. The filar micrometer was used, and the height may be a little too great on account of the distortion of the image; in order to see the whole prominence, the slit had to be opened to $2^{mm}.5$, and the fact that this was possible testifies to the extraordinary brightness of the prominence. After the measurement was completed, its form had again completely changed. Its more prominent features are represented in Fig. VII, from a hasty sketch made at the telescope at $10^h 11^m$. Seven successive transits across the slit were then observed, during which the ascent of the prominence was completed. The observed heights are given in the following table, with the corresponding times and computed velocities of ascent.

Measure	Greenwich Mean Time			Height	Velocity
	h	m	s	"	km
1	10	14	22.4	472	
2		15	10.6	513	842
3		16	3.4	525	16
4		16	56.8	563	516
5		17	50.0	594	422
6		19	2.0	616	221
7		20	11.0	688.3	746
8		20	59.6	493 (uncertain)	
9		29	20.0	525 "	
10		30	13.0	398 "	
11		46	39.	196	

While the protuberance was passing across the somewhat

narrowed slit, I noticed in many places considerable displacements, sometimes toward the red and sometimes toward the violet. The small clouds, which may be seen in the drawing floating above the principal mass, rose with especial rapidity, and indicated a large motion of recession,—according to one measurement 181^{km} per second. The fragments endowed with this extraordinary motion were found above the great arch shown in Fig. VII, in a position angle of approximately $95°$; when the third transit was observed they had already faded greatly, so that some uncertainty attaches to the height obtained for them. At the eighth transit they could no longer be observed. The height obtained was only $493''$; further transits gave $525''$ at $29^m\ 20^s$, and $398''$ at $30^m\ 5^s$, but these last values are quite uncertain, and are added merely to show that the highest parts of the protuberance were rapidly dissolving. At $10^h\ 47^m$ the height reached by the part inclined toward the equator (Fig. VIII) was $196''$. The other parts had already vanished, as shown by the figure, and at great heights also nothing could be detected. At $3^h\ 45^m$ a new prominence, consisting of very bright flame-like filaments, had risen over position angle $93°–96°$ to a height of $60''$, and at $83°$ there was visible only a small prominence about $20''$ high. The entire colossal form therefore developed in an interval of twenty minutes, and had dissolved with still greater rapidity. The velocity of ascent seems to have altered incredibly in the short interval of $1^m–2^m$ between the observations, and it is probable that these changes are rather to be ascribed to inequalities in the rate of dissolution at the summit. The particularly striking change indicated by the second transit would be satisfactorily accounted for, if it were allowable to assume an error of one second in the noted time—an assumption, however, for which no justification can be discovered in the observations themselves. Instead of the velocities given in the table (842, 16, 516^{km}), we should then have 391, 355, 516^{km}.

Although the individual velocities may be subject to some uncertainty on account of the dissolution which accompanied the

rise of the prominence, we have, in the mean value of the ascent during the eight minutes occupied by the seven transits, an average result from which trustworthy conclusions may be drawn. From an ascent of $216''.3$ in $349^s.6$ we obtain a velocity of 448^{km} per second, which is a minimum value, depressed by the effect of dissolution. A correction of $4''-5''$ should really be added to the height $688''.3$, increasing the value of the latter, since the highest fragments of the prominence did not pass exactly over the part of the slit which was tangent to the Sun's limb, but the correction is in this case of no importance. If we use the earlier observations, for which the times are less accurate, to determine the velocity, the values obtained are very materially greater.

The Sun-spot connected with this latter eruption betrayed a considerable motion in longitude, and I therefore caused my assistant, Herr P. J. Schreiber, to whom the observations of Sun-spots are entrusted, and who made the accompanying drawings of spots, to determine its exact position at different times. On September 30 the longitude was $303^\circ.5$ and the latitude $+21^\circ.3$. The following table gives the difference between the observations and Spörer's rotation formula:

Sept. 30 to Oct. 1	$-1^\circ.25$
Oct. 1 to Oct. 2	$-1\ .35$
Oct. 2 to Oct. 3	$-0\ .59$
Oct. 3 to Oct. 4	$-0\ .43$
Oct. 4 to Oct. 5	$+0\ .36$
Oct. 5 to Oct. 6	$-0\ .59$
Oct. 6 to Oct. 7	$+0\ .17$

It appears, therefore, that in the earlier days there was in fact a considerable proper motion of the spot, amounting to about 600^{km} per hour.

In both of the cases, which have been described above, we find eruptions standing in close relationship to a group of Sun-spots very nearly on the limb of the Sun. Eruptions on a great scale occur only in the Sun-spot zones, usually, but not always, over a disturbed region of spots. Especially deserving of attention is the grouping of the component strips of the prominence in forms so exactly inclined to the Sun-spot group, and the cor-

responding disposition of the phenomenon during its entire course. There is nothing new in the convergence of the strips toward the Sun-spot; an appearance of this kind, more or less marked, is always observed over a spot in the course of development on the Sun's limb, so that from this characteristic structure of a prominence the approach of a spot to the eastern limb of the Sun can be predicted. In the cases before us the phenomenon is especially striking, and leads to the supposition that processes of less intensity, but not essentially different nature, are going on above the spots which we daily observe on the face of the Sun.

In forming a judgment as to the nature of the phenomena we must account also for these appearances. The strips which are so characteristically inclined must have a radial arrangement with reference to the spots, in which the central strips are hidden or shortened by perspective, while those on the sides are strengthened by superposition. It cannot be denied that this arrangement points to the existence of currents in the solar atmosphere, directed either toward the interior of the spot or outward from it. In view of the appearances which accompany the ascent of eruptive prominences, we must, if we wish to avoid the assumption of oppositely directed motions in close proximity, consider an outward current as the more probable. We need not therefore also assume that monstrous protuberances, which in extreme cases may even attain a volume equal to the tenth part of the Sun's, flow out through the small center of the spot from the interior regions, although the enormous extent does not offer any absolute difficulty. Direct observation simply does not support such an assumption. Although we almost always see protuberances rising from a broad base as a uniform mass, this fact can also be explained by supposing that the foot of the protuberance is not on the solar limb; but those regions which by the intensity of their phenomena make themselves known as centers of eruption, and which by their inconsiderable height are visible only when they are exactly on the limb, are almost never observed over a spot, but usually close beside it.

The appearance of all the numerous great eruptions which I have observed has been such as would be produced by a kind of explosion over a region of spots, which, seizing upon a prominence already developed, hurls it upward from the surface, tears it to pieces, and brings it to a speedy end. This conception also accords well with the appearances which we are now considering; it is by no means asserted, however, that an explosion actually occurred.

A remarkable example apropos to this subject is afforded by the eruption of September 5, 1888. I had observed the eruptive region over half an hour, on account of the metallic lines which appeared in it, without noticing any change; suddenly, in about one minute, the prominence, which was only about 20″ high, began to rise, and in an interval of nineteen minutes it reached a height of $111{,}000^{km}$. Often great prominences, which had remained almost unchanged for days, could not be found a few hours later; only the clear edge of the Sun was in their place—not a fragment of them remained.

These phenomena are interpreted in very different ways. I have little fear of being mistaken when I say that there is not a single observer of prominences who regards any one of the later theories as tenable.

That enormous translatory velocities of 200 and more kilometers per second occur in the matter on the Sun, I regard as definitely proved by the observed displacements of spectral lines, and if these great horizontal velocities are admitted, vertical motions of the same order are not to be set aside as incredible. A very weighty objection to the occurrence of vertical changes of level has recently been brought forward and numerically treated by Herr Egon v. Oppolzer. He shows that even moderate changes of level of only 1″ are sufficient to cause a difference of temperature of 13,000°, in consequence of the adiabatic changes of pressure. According to this computation, the protuberance of September 30 must have cooled some 9,000,000° in rising to a height of 688″. Herr v. Oppolzer's argument is directed against the possibility of a gaseous mass *sinking*

toward the Sun; a sinking motion must, if rapidly begun, be resisted by the elevation of temperature. On the ground of observation I can only confirm this result of computation in the most emphatic manner; downward motions are in fact, very seldom observed in prominences, and may then arise from quite peculiar conditions. In general, the falling back of masses which have been thrown upward, an occurrence so familiar in our daily experience, is never observed on the Sun. Although observers occasionally speak of forms resembling a fountain, no more significance should be ascribed to such a comparison than to the tree-like forms which are more frequently mentioned. The difficulties which the researches of Herr v. Oppolzer have opposed to ascending as well as descending motions will constitute one of the objects of my investigations, of which I shall hope to say more in the near future.

KALOCSA, HUNGARY,
December 4, 1895.

THE ALGOL VARIABLE *B. D.* + 17° 4367.

By Edward C. Pickering.

Below are given the heliocentric times of minima of the Algol star *B. D.* + 17° 4367 expressed in Greenwich Mean Time during the year 1896. They are computed by means of the formula, *J. D.* 2412002.500 + 4.8064 *E*. It is not probable that the period will be changed materially by later observations, but the times of minima may be altered by a constant amount of several minutes if the rates of increase and decrease are different. For nearly two hours before and after the computed minima the star may be expected to be fainter than the twelfth magnitude, two magnitudes and a half fainter than its normal brightness, and varying very rapidly. The value of *E* for the first date is 325 and for the last 400.

Jan.	5	13^h	55^m	April	5	21^h	38^m	July	6	5^h	21^m	Oct.	5	13^h	05^m
"	10	9	16	"	10	16	59	"	11	0	43	"	10	8	26
"	15	4	37	"	15	12	20	"	15	20	04	"	15	3	47
"	19	23	58	"	20	7	42	"	20	15	25	"	19	23	08
"	24	19	20	"	25	3	03	"	25	10	46	"	24	18	29
"	29	14	41	"	29	22	24	"	30	6	07	"	29	13	51
Feb.	3	10	02	May	4	17	45	Aug.	4	1	29	Nov.	3	9	12
"	8	5	23	"	9	13	06	"	8	20	50	"	8	4	33
"	13	0	44	"	14	8	28	"	13	16	11	"	12	23	54
"	17	20	06	"	19	3	49	"	18	11	32	"	17	19	15
"	22	15	27	"	23	23	10	"	23	6	53	"	22	14	37
"	27	10	48	"	28	18	31	"	28	2	15	"	27	9	58
Mar.	3	6	10	June	2	13	52	Sept.	1	21	36	Dec.	2	5	19
"	8	1	31	"	7	9	14	"	6	16	57	"	7	0	40
"	12	20	52	"	12	4	35	"	11	12	19	"	11	20	01
"	17	16	13	"	16	23	57	"	16	7	40	"	16	15	23
"	22	11	34	"	21	19	18	"	21	3	01	"	21	10	44
"	27	6	56	"	26	14	39	"	25	22	22	"	26	6	06
April	1	2	17	July	1	10	00	"	30	17	43	"	31	1	27

Harvard College Observatory,
Cambridge, Mass., February 3, 1896.

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PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XII.

By Henry A. Rowland.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6090.010		0000	6105.995		000
6090.186		0000	6106.651		0000
6090.287		0000	6106.840		00
6090.429	Fe	2	6107.070		0000
6090.722		0000 N	6107.309		0000
6091.395		0	6107.560		0000
6091.580		0000	6108.108		0000
6091.714		0000	6108.334 s	Ni	6
6091.945		000	6108.503		0000
6092.133		1	6108.675		0000 d?
6092.737		0000	6109.105		0000
6093.030		000	6109.545		0000
6093.366		00 N	6110.042		0000
6093.580	A?	0000	6110.555		0000 d?
6093.864	Fe	2	6111.005		0000
6094.075		0000	6111.290 s	Ni	2
6094.590	Fe	1	6111.545		0000 N
6095.118		0000	6111.872	V	0 d?
6095.575		0000	6112.235		0000
6096.360		0000 N	6112.500		0000 N
6096.880	Fe	3	6112.621		0000
6097.095		0000	6113.142		0
6097.312		0000	6113.340		0000
6097.505		000	6113.538		0
6098.000		0000	6114.075		0000
6098.465		0	6114.600		0000 N
6098.870		00	6115.010		0000
6099.888		0000 N	6115.960		000 N
6100.490		00	6116.268		0000
6102.392 s	Fe	6	6116.397 }s	Ni	4
6102.635		0000 N d?	6116.455 }	Fe	1
6102.937 s	Ca	9	6116.665		0000
6103.289		0000	6116.900		0000Nd?
6103.400 }s	Fe	4	6117.210		00
6103.514 }		1	6117.415		000
6103.690		000	6117.623		0000
6103.796		0000	6117.846		0000
6104.830		0000	6118.028		0000
6105.349		0	6118.139		0000
6105.730		0000	6118.320		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6119.385		0000	6136.829 s	Fe	8
6119.527		0000	6137.210	Fe	3
6119.740	V	1	6137.428		0000
6119.970	Ni	0	6137.505		000
6120.245		0000	6137.710		000
6120.460		00	6137.915	Fe	7
6120.751		0000	6138.266		0000 N
6121.010		0000	6138.725		00 N
6121.215		000	6139.864		000 N
6121.541		0000	6141.020		0000
6121.986		0000	6141.265		000
6122.434 s	Ca	10	6141.595		0000
6122.830		000	6141.938 s	Fe, Ba	7
6123.468		0000	6142.225		0000
6123.730		0000	6142.420		0000
6124.287		0000	6142.700		1
6124.703		0000	6143.044		0000 N
6125.236		1	6143.390		0000 N
6125.522		0000	6143.976		0000 N
6126.075		0000 N	6144.550		0000
6126.435	Ti	1	6144.988		0000
6126.665		0000	6145.228		2
6127.001		0000	6145.616		000 N
6127.684		0000 N	6146.445		000
6127.851		0000	6146.882		0000
6128.124	Fe	3	6147.380		0000 N
6128.320		0000	6147.702		0000
6129.190	Ni	1	6147.950		2
6129.430		000	6148.040	Fe	3
6129.740		000 N	6148.300		0000 N
6129.940		000	6148.480		0000
6130.145		0000	6148.870		000
6130.344	Ni	1	6149.209		0000
6130.560		0000	6149.458		2
6131.181		0000 N	6149.766		0000
6131.490		0000 N	6149.950		0000 N
6131.785		0	6150.360	V	0 N d?
6132.070		0	6150.840		0000
6132.490		0000 N	6151.052		0000
6132.704		0000	6151.550		0000
6133.020		0000 N	6151.834	Fe	4
6133.440		000 N	6152.054		0000
6133.785		0000 N	6152.226		0000
6134.175		00	6152.520		000 N
6134.810		000 N d?	6152.854		0000
6135.280		0000 N	6153.055		0000
6135.580	V	00 N	6153.560		0000 N
6135.985	Cr	00 N	6154.129		0000 N
6136.280		0000	6154.438 s	Na	2
6136.500		0000	6154.650		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6154.898		0000 N	6173.276		0000 N
6155.101		0000	6173.553 s	Fe	5
6155.350		7	6173.782		0000
6155.450		000	6174.065		0000
6155.699		0000	6174.948		0000 N
6155.918		000	6175.370		0000
6156.240		00	6175.584	Ni	3
6156.490		000 N	6175.807		0000 N
6157.010		000 N	6176.011		0000
6157.450		0000 N	6176.426		0000
6157.630		000	6176.669		0000
6157.945	Fe	5	6176.815		0000
6158.130		0000	6177.027 s	Ni-	5
6158.380		000 N	6177.255		0000
6158.888		0000	6177.463		0
6159.300		0000	6177.747		0000
6159.590		0	6177.977		0000
6159.910		0000 N	6178.730		0000 N
6160.437		0000	6179.610		000
6160.660		0000	6180.279		0000
6160.956 s	Na	3	6180.420 s	Fe	5
6161.176		0000	6180.587		0000
6161.298		0000	6182.849		0000
6161.503	Ca	4	6183.334		0000
6161.844		0000 N	6183.779	-, A (wv)?	0 Nd?
6162.390 s	Ca	15	6184.080		000
6163.630	Ni	2	6185.918	Fe	1
6163.765	Fe	1	6186.424	-, A (wv)?	00 N
6163.968	Ca	3	6186.928	Ni	2
6164.777		0000 N	6187.618		00
6165.378		0000	6188.210	Fe	4
6165.577	Fe	3	6188.679		0000 Nd?
6165.760		0000	6189.200	Co, A (wv)?	00 Nd?
6166.105		0000	6189.594		0000 N
6166.266		0000	6190.611		000
6166.410		0000	6190.873		0000
6166.651	Ca	5	6191.048		0000
6168.083		0000 N	6191.393 s	Ni	6
6169.002		0000	6191.779 s	Fe	9
6169.249 s	Ca	6	6194.440		0000
6169.529		0000	6194.633		0 N
6169.778 s	Ca	7	6195.080		0000
6170.178		000 N	6195.663		0 N
6170.420	V	0000 N	6196.373		0000
6170.730	Fe-Ni	6	6198.107		0000
6171.028		0000	6198.864		0000
6171.215		0000	6199.398	V	0
6171.443		0000	6199.718		00
6172.161		0000	6199.985		0000
6172.945		0000 N	6200.160		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6200.527 s	Fe	6	6230.551		0000
6200.690		0000	6230.943 s	V-Fe	8
6201.176		0000	6231.211		0000
6203.554		0000	6232.856	Fe	3
6204.698		0000	6233.082		0000
6204.825	Ni	1	6233.408		000
6205.360		0000 N	6233.720		0000Nd?
6207.460		000	6236.816		0000 N
6207.916		0000	6237.534 s		3
6208.425		000	6238.598		2
6208.783		00	6239.234		0000
6209.100		0000	6239.585		00
6209.962		0000 N	6239.980		0000
6210.895		00 N	6240.165		00
6212.275		00 N	6240.370		0000
6212.479		0000	6240.530		00
6213.644 s	Fe	6	6240.863	Fe	3
6213.840		0000	6241.065		0000
6214.080	V	000	6243.055	V	000
6214.885		000 N	6243.320		1
6215.231		0000	6243.540		0000 N
6215.360	Fe	5	6244.033		2
6215.630	Ti	000	6244.335		000 N
6215.931		0000	6244.686		2
6216.103		00 N	6245.137		0000 N
6216.567		1	6245.413		0000 N
6216.810		0000	6245.832		1
6217.900		000	6246.100		0000 N
6219.494 s	Fe	6	6246.535 s	Fe	8
6219.730		0000	6247.774		2
6220.150		0000	6249.122		000
6220.450		000	6249.409		0000
6220.700		000	6249.710		0000
6221.005	Fe	0	6249.860		000
6221.222		0000	6251.495		0000
6221.552	Fe,-	00 Nd?	6252.048	V	00
6221.850		0000	6252.278		0000
6223.652		0000 N	6252.410		0000 N
6224.198	Ni?	1	6252.773 s		7
6224.407		0000	6254.050		00
6224.715	V	000	6254.382 s		1
6225.380		0000 N	6254.456	Fe	5
6225.700		0000	6255.000		0000 N
6226.527		0000 N	6255.805		0000 N
6226.951	Fe	1	6256.168	Fe	00
6227.770		00	6256.572 s	Ni-Fe	6
6229.437	Fe	1	6257.090		0000 N
6229.852		0000	6257.802		0000 N
6230.050		0000	6258.322	Ti	2
6230.312	Ni	0	6258.570	V	000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6258.780		00	6278.012		000
6258.927	Ti	3	6278.177	A(wv)	0000
6259.144		0000	6278.303[2]	A(O)	4 d
6259.448		0000	6278.579	A(wv)	00 N
6259.800		00	6278.760		0000
6259.980		0000	6278.907		0000
6261.316 s	Ti	1	6279.084	A(O)	2
6261.501	V	0000	6279.308	A(O)	3
6261.760		0000 N	6279.530	A(wv),-	00 Nd?
6262.173		0000	6279.754	A(wv)	0000
6262.458		0000 N	6279.946		0 d
6263.164		0000 N	6280.108	A(O)	2
6265.015		0000	6280.305		0000
6265.348 s	Fe	5	6280.460		0000
6265.573		0000	6280.598	A(O)	2
6265.820		000	6280.833	Fe	3 d
6266.223		0000 N	6281.025		0000
6266.550		000	6281.228		0000
6267.042		0000	6281.387	A(O)	1
6267.424		0000 N	6281.575		0000
6267.860	-, A (wv)	000	6281.835		000 N
6268.040		000	6282.004		0000
6268.433		0000	6282.164	A(O)	2
6268.819		0000	6282.350	A?	0000
6269.080	V	000 N	6282.502		0000
6269.630		0000	6282.740	A(wv)	000
6270.200		000	6282.808		000
6270.442	Fe	3	6282.933	Co- A (O)	2
6270.628		0000	6283.035		000
6271.112		0000 N	6284.002	A(O)	1
6271.486	Fe	0	6284.210		0000
6271.703		0000	6284.748	A(O)	0
6271.970		000	6284.993		0000
6272.157	A(wv)	0000	6285.384	V	00 N
6272.623	A(wv)	000	6285.878		0000 N
6272.870		000	6286.031	A(wv)	00
6273.306		0000 N	6286.359		0
6274.170		000 N	6287.009		0000 N
6274.870		00	6287.494		000 N
6275.478	A(wv)	000	6287.953[3]	A(O)	1
6276.450		0000 N	6288.154	A(wv)?	000 N
6276.690		0000	6288.530		000 Nd?
6276.815[1]	A(O)	2 d	6288.839		0000
6277.021	A(O)	1	6288.955		0000
6277.164	A?	00 N	6289.384	A(wv)?	000
6277.359	A?	000	6289.606	A(O)	1
6277.513	A(O)	2	6289.790		0000
6277.639	A(O)	1	6290.106		0000 N
6277.701	A(O)	1	6290.427	A(O)	2
6277.837	A(O)	1	6290.750		000 N

[1] First line in the head of the alpha group, due to atmospheric oxygen.

[2] Principal line in the head of the alpha group.

[3] First line in the tail of the alpha group.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6291.184	Fe	4	6308.090		000 N
6292.373	A (O)	2	6309.040		000 N
6292.572		0000	6310.101	A (O)	2
6292.825	A (wv)	0000 N	6310.487		00 Nd?
6293.030	V	000	6310.698		0000
6293.170	A (O)	3	6310.848	A (O)	1
6293.370		0000	6311.055		0000
6294.155		00 Nd?	6311.451		00 Nd?
6294.875	A (wv)	0000 N	6311.722	Fe	1
6295.242		0000	6311.936		0000 N
6295.389	A (O)	3	6312.456		00 N
6295.590		0000	6312.980		000
6295.860	A (wv)	0000 N	6314.077		0000 N
6296.022		0000	6314.449	A (O)	0
6296.170	A (O)	3	6314.876	Ni	4
6296.360		0000	6315.189	A (O)	0
6296.582	V	0000	6315.517	Fe	2
6296.715		0000	6315.631		00
6297.471	A (wv)?	0000	6315.854		0000
6297.517		0000	6316.028	Fe	1
6298.007	Fe	5	6316.245		0000
6298.295		0000	6316.510	A (wv)	0000 N
6298.513		0000	6316.816		0000
6298.666	Co, A (O)	2	6317.440	A (wv)	0000 N
6298.854		0000	6317.670		0000
6299.436	Fe, A (O)	3	6318.239	Fe	6
6299.625	A (wv)	000	6318.524		0000 N
6299.805		0	6318.919		1
6300.535		000	6319.082	A (O)	0
6300.904		000	6319.274		0000
6301.718	Fe	7	6319.460		0
6302.056		0000	6319.690	-, (wv)?	000
6302.209	A (O)	2	6319.806	A (O)	0
6302.401		0000	6320.250	A (wv)	0000 N
6302.709	Fe	5	6320.660		000
6302.975	A (O)	2	6321.070		00
6303.159		0000	6321.505	A (wv)	0000
6303.700		000 N	6322.380	Ni	0
6303.985		000 N	6322.550		0000
6304.545		000 N	6322.907	Fe	4
6305.070		0000 N	6323.244		0000 N
6305.525		000 N	6323.688		0000 N
6305.878		0000	6323.957	A (O)	00
6306.024	A (O)	2	6324.096	A (wv)	0000
6306.201		0000	6324.709	A (O)	00
6306.430		0000	6324.894		0000
6306.619		0000	6325.382		0000
6306.780	A (O)	2	6325.748		0000 N
6306.950		0000	6327.038		0000
6307.763		0000 N	6327.485		0000

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FLUORESCENCE OF SODIUM AND POTASSIUM VAPORS AND ITS SIGNIFICANCE IN ASTROPHYSICS.[1]

By EILH. WIEDEMANN and G. C. SCHMIDT.

IN the case of unmixed vapors fluorescence has been proved to exist for iodine by E. v. Lommel,[2] and we have shown[3] that it also exists for the vapors of numerous organic substances. In our recent experiments we have studied the behavior of metallic vapors with respect to the same property.

I. ARRANGEMENT OF APPARATUS.

The arrangement of the apparatus used in these experiments was as follows: Rays of sunlight fell upon a lens L of about 5^{cm} focal length, by which they were converged to a focus σ inside a spherical bulb K filled with vapor. At one side of the bulb was

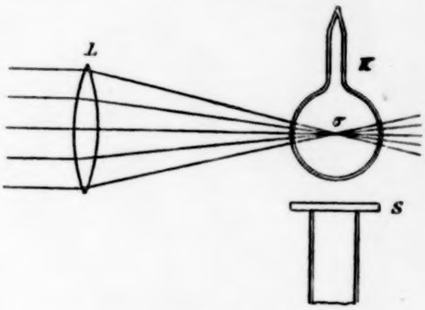


FIG. 1.

placed a spectroscope fastened by its legs to a vertical board in such a position that the slit and refracting edge of the prism were horizontal. The conical bearing in its base allowed the spectroscope to be turned on its axis, so that the collimator

[1] "Fluorescenz des Natrium-und Kaliumdampfes und Bedeutung dieser Thatsache für die Astrophysik."—*Sitz. d. Phys. med. Soc. Erlangen*, November 12, 1895.

[2] *Wied. Ann.* **19**, 856, 1883.

[3] *Wied. Ann.* **56**, 18, 1895.

could be directed to the cone of fluorescent light in the interior of the bulb.

The introduction of sodium, potassium and other metals into the bulbs, which were usually made of hard glass, was effected in the following manner :

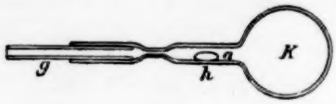


FIG. 2.

A small quantity of metal was first placed in the bulb; the neck was then drawn out, and a tube of soft glass cemented into its end, connecting it with a mercury air-pump. The metal was then brought into the position *a*, and gently heated during continuous pumping, in order to drive out all moisture and carbon dioxide, while in some cases the bulb was also cleansed by filling it several times with hydrogen. The heat was then increased, and after a suitable quantity of metal had distilled over into the bulb *K*, the neck was sealed off at its narrowest part by melting. In most of the experiments the diameter of the bulb was 5^{cm}, so that the whole bulb was easily enveloped in a flame. We have also used bulbs of soft glass, and bulbs of other dimensions than the above, but the optical phenomena were always the same. In the case of the alkali metals much trouble was caused by the changes which their vapor produced in the glass, even in short periods of time; the bulbs blackened and browned so that they frequently had to be replaced by new ones.

2. RESULTS.

The experiments showed that sodium and potassium vapors have a bright fluorescence,—the former green, the latter deep red. The fluorescence of these vapors can also be seen very beautifully when they are introduced into the arc of an electric lamp.

In the case of the less volatile metals we have so far been unable to demonstrate the existence of fluorescence with entire

certainty, although cadmium vapor seems to show a green fluorescent color immediately over the surface of the boiling metal. The failure of these attempts is however to be attributed in part to the feeble intensity of winter sunlight, and we shall naturally repeat the experiments in the summer.

The spectrum of the fluorescent light of sodium vapor is constituted as follows:

——λ 496.	Above λ 496 almost nothing can he seen.
λ 496 — λ 540.	Green fluted band, made up of separate dark and bright lines.
λ 540 — λ 602.5.	Dark band.
λ 602.5 — λ 675.	Bright red band.
λ 675.	Limit of the red.

In addition the bright sodium line appeared at the less refrangible end of the dark band λ540 — λ602.

The bright sodium line did not come from the flame used for heating the bulb, for it remained brightly visible when the flame was removed; nor did it arise from chemical processes going on in the bulb, for it disappeared instantly on cutting off the sunlight.

The spectrum of the fluorescent light of sodium vapor[1] is therefore made up of three parts: (1) The non-fluted band in the red, (2) the fluted band in the green, (3) the bright sodium line in the yellow.

While solid and liquid fluorescent bodies have fluorescence spectra which consist of broad, diffuse, continuous bands, we here meet with fluted bands also, such as are shown by other gases under the influence of the electric discharge, and with single lines.

The fluorescence spectrum of potassium has a deep red band at λ615 — λ695. Above this the background is dark, although

[1] A comparison of these fluorescence spectra with the spectra which appear when sodium vapor is heated (Evershed, *Phil. Mag.* (5) **39**, 460, 1895), shows the existence of certain relations, and the same is the case, with both sodium and potassium, if the positions of the fluorescence spectra are compared with the absorption-band spectra measured by H. E. Roscoe and A. Schuster (*Proc. Roy. Soc.* **22**, 262, 1894); in both cases the emission spectrum seems to be displaced toward the red.

there is a slight brightening in the green, due, perhaps, to the presence of some sodium vapor.

We were unable to prove that the bright potassium lines were present, but their absence may have been due to insufficient intensity of the incident light.

The spectrum of the fluorescent light of lithium could unfortunately not be observed, since lithium, when it is heated in glass vessels, attacks the glass, with production of light. On further heating the vapor given off by the residue shows merely the green fluorescence of sodium. Attempts to obtain an electro-luminescence from lithium, enclosed in vacuum tubes and subjected to electric discharges, were unsuccessful for the same reason.

3. VALIDITY OF STOKES' LAW FOR THE FLUORESCENT LIGHT OF METALLIC VAPORS.

We have also tried to ascertain whether Stokes' law holds good for metallic vapors, *i. e.*, whether the excited rays of light are less refrangible than the exciting rays. To this end a somewhat narrow strip in the spectrum formed by a prism was isolated by screening out the other rays, and its light was concentrated by a lens on the vapor which filled the bulb.

With sodium vapor the intense green fluorescent light was excited most powerfully by green-blue rays, and the red by yellow and red rays. With potassium vapor the deep red light was excited by red rays.

These experiments show that there were at least no very marked deviations from Stokes' law.

4. APPLICATIONS TO ASTROPHYSICS.

We desire to point out briefly the importance in astro physical problems of the observations which are described above and which show that metallic vapors are capable of exhibiting fluorescence. A more complete discussion must be reserved for another place.

We know that the Sun's atmosphere contains the vapors of

different metals, which are illuminated by the Sun; they must therefore fluoresce, and that very brightly. We must not forget that the intensity of the exciting light in the vicinity of the Sun is very much greater than at the surface of the Earth, and hence, also, that of the fluorescent light which is excited. These radiations due to fluorescence do not obey Kirchhoff's law.

The emitted fluorescent light is made up of continuous and fluted bands and single lines. In the case of a mixture of many different metals the bands would blend together into a continuous spectrum; the delicate, and often scarcely perceptible flutings of different substances would be superposed and lost. The sharp lines, on the other hand, would remain separately visible. In this way we should have, for example, the simplest possible explanation of the spectrum of the corona, which consists of a continuous spectrum and individual bright lines. It would then be unnecessary to assume a continuous excitation of luminosity by electrical vibrations, which nevertheless in many cases certainly play an important part. Applications of these results to the theory of the chromosphere, certain forms of prominences, etc., readily suggest themselves.

But in all astrophysical and other phenomena relating to radiation an especial discussion will be necessary, not only with reference to what part of the radiation arises solely from an elevation of temperature, and what part from luminescence, but it will also be necessary to determine when we have to deal with a luminescence excited by light, *i. e.*, with fluorescence. Here the conditions are comparatively simple and more easily realized than in other cases within the reach of experiment.

5. GENERAL REMARKS.

The fluorescence that we have investigated, that of rarified potassium and sodium vapors, may be the simplest possible case of this phenomenon. In the first place the light-emitting molecules of the body under investigation, when it is in the gaseous state, are almost uninfluenced by the action of neighboring molecules,—if we except the short times when two or more

molecules are mutually within the spheres of their respective attractions, in which instants their relations are those of molecules in solid and liquid bodies. Further, sodium and potassium vapors are monatomic, at least according to the determinations of vapor densities which have been made hitherto. The fact that these vapors can give banded as well as line spectra constitutes a new point of departure for theoretical investigations of fluorescence, especially when it is desired to take into account the intramolecular processes which are the cause of the phenomenon.

6. RESULTS.

The fluorescence of sodium and potassium vapors is bright; the former green, the latter red. The fluorescence spectrum of sodium vapor contains continuous and fluted bands, and also the yellow line of sodium.

Stokes' law is probably valid for the fluorescence of metallic vapors. The fluorescence of metallic vapors gives a means of explaining a series of astrophysical phenomena.

(Experiments with helium and argon are in progress.)

Minor Contributions and Notes.

HARVARD COLLEGE OBSERVATORY, CIRCULAR NO. 5.

WELLS' ALGOL VARIABLE.

A MINIMUM of the Algol star, *B. D.* $+17°$ 4367, occurred, as predicted in *Circular No. 4*, on the afternoon of January 5, 1896. Through the courtesy of Professor Young, observations were obtained at Princeton by Professor Taylor Reed, with the 23-inch equatorial. It was also observed by Mr. W. M. Reed at Andover. Preparations had been made at this Observatory to obtain a series of photographic images of it automatically, each having an exposure of five minutes, to observe it photometrically with the 15-inch equatorial, and also visually with the 12 and 6-inch equatorials. Unfortunately, owing to clouds, few observations were obtained, but these serve to show that the star was faint and diminishing in brightness as expected. Similar preparations were made for the next minimum, January 10, but again clouds prevented observation.

The observations so far obtained show that its time of minimum, uncorrected for the velocity of light, can be closely represented by the formula *J. D.* $2412002.500 + 4.8064\, E$. The uncertainty in the period does not exceed a few seconds, and will probably be known within a single second as soon as the form of light curve is determined. For nearly two hours before and after the minimum it is fainter than the twelfth magnitude. It is impossible, at present, to say how much fainter it becomes or whether it disappears entirely. It increases at first very rapidly and then more slowly, attaining its full brightness, magnitude 9.5, about five hours after the minimum. One hundred and thirty photographs indicate that, during the four days between the successive minima, it does not vary more than a few hundredths of a magnitude. The variation may be explained by assuming that the star revolves around a comparatively dark body and is totally eclipsed by it for two or three hours, the light at minimum, if any, being entirely that of the dark body. The conditions resemble those of U Cephei, which appears to be totally eclipsed by a relatively dark body two and a half magnitudes fainter than itself, but having a diameter

at least one half greater. The variation in light of *B. D.* $+ 17^\circ$ 4367 is more rapid than that of any other star hitherto discovered, and as its range is greater than that of any known star of the Algol type, its form of light curve can be determined with corresponding accuracy. U Cephei is second in both these respects.

THE NEW STAR IN CENTAURUS.

In *Circular No. 4*, insert "it" before "follows" in the ninth line. This word was given correctly in the printer's copy, but was omitted in setting the type. The correction was telegraphed to those astronomers who, it was expected, would use it.[1] The Nova follows the nebula *N. G. C.* 5253, and is north of it. The nebula is assumed to be *C. DM.* -31° 10536, mag. 9.5, with which it was originally identified. As seen with a low power the nebula cannot readily be distinguished from a star. Its magnitude on the Cordoba scale by comparison with adjacent stars was estimated by Mr. Wendell as 9.7, and it could hardly have been overlooked in preparing the Cordoba Durchmusterung, in which many adjacent fainter stars are given. The new star could not have been observed at Cordoba unless we assume, first, that it was bright at that time, although invariably too faint to be photographed on fifty nights distributed over six years, and secondly, that the nebula was overlooked at Cordoba while observing fainter objects in the same region. Even if we make these assumptions, the new star still falls in the same class as T Coronae, which was observed in the northern Durchmusterung several years preceding its appearance as a new star.

The various positions of *N. G. C.* 5253 for 1875 are as follows:

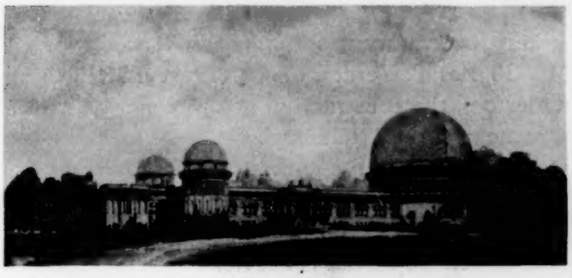
Dreyer's New General Catalogue	R. A. $= 13^h\ 32^m\ 51^s$	Dec. $= -31^\circ\ 0'.2$
Cordoba Durchmusterung	R. A. $= 13^h\ 32^m\ 49^s.6$	Dec. $= -31^\circ\ 0'.3$
Plate B 13965	R. A. $= 13^h\ 32^m\ 50^s.2$	Dec. $= -31^\circ\ 0'\ 23''$
Plate B 14072	R. A. $= 13^h\ 32^m\ 50^s.0$	Dec. $= -31^\circ\ 0'\ 21''$

The positions of the Nova derived from these plates differ from each other by only $0^s.1$ in right ascension and $1''$ in declination. The mean position for 1875 is R. A $= 13^h\ 32^m\ 51^s.8$, Dec. $= -30^\circ\ 59'\ 58''$. It will be noticed that according to these measures, the Nova follows *N. G. C.* 5253 by $1^s.7$, and is $24''$ north.

EDWARD C. PICKERING.

January 31, 1896.

[1] The wording of the *Circular* in this JOURNAL was correct.



YERKES OBSERVATORY—WILLIAMS BAY, WIS.

YERKES OBSERVATORY, UNIVERSITY OF CHICAGO. BULLETIN NO. 1.

THE present is the first of a series of *Bulletins* which will be printed at irregular intervals by the Yerkes Observatory for the purpose of making announcements which require immediate or special publication. These will include statements with regard to the work of the Observatory, brief descriptions of new buildings and instruments, and other notes on miscellaneous matters of interest. The *Bulletins* will be published in the *Astrophysical Journal.* They will also be distributed separately, without charge, to a limited number of scientific men and institutions likely to find them of service in connection with their work.

ORGANIZATION OF THE YERKES OBSERVATORY.

GEORGE E. HALE,	*Director.*
S. W. BURNHAM,	*Astronomer.*
E. E. BARNARD,	*Astronomer.*
F. L. O. WADSWORTH,	*Astrophysicist.*
[1] T. J. J. SEE,	*Instructor at The University.*
[1] KURT LAVES,	*Assistant at The University.*
FERDINAND ELLERMAN,	*Assistant.*
G. WILLIS RITCHEY,	*Optician.*
EDMUND KANDLER,	*Mechanician.*
WILLIAM GAERTNER,	*Mechanician.*

[1] Messrs. See and Laves will give undergraduate and graduate instruction in theoretical and practical astronomy at The University in Chicago, and superintend the Student's Observatory, which will be equipped for instruction in practical astronomy preparatory to work at the Yerkes Observatory. For a full statement of the courses of instruction offered at The University and the Yerkes Observatory see the *Annual Register* of The University of Chicago.

BUILDING AND INSTRUMENTS.

The Yerkes Observatory was founded in 1892 through the munificence of Mr. Charles T. Yerkes, of Chicago. In that year Mr. Alvan G. Clark undertook the construction of an object glass of forty inches aperture for the principal telescope of the Observatory, and Messrs. Warner & Swasey were given a contract for the equatorial mounting. The latter was completed in the following year, and exhibited by its makers at the Columbian Exposition. It is similar to the mounting of the 36-inch Lick telescope, but is heavier and more rigid, and many improvements have been introduced. An important feature, long ago suggested by Grubb and others, but apparently employed for the first time in this telescope, is a system of electric motors, by means of which the various motions, etc., are effected. The object-glass has recently been tested by Professor James E. Keeler, who acted at the request of the Director as the "expert agent" called for by the contract. The definition was found to be fully equal to that of the Lick telescope, while the light-gathering power is considerably greater. (See *Astrophysical Journal*, **3**, 154, 1896.)

The attachments of the Yerkes telescope will include:

1. A position micrometer by Warner & Swasey.

2. A solar spectrograph, for micrometrical and photographic investigations of the spectra of solar phenomena.

3. A spectroheliograph, for photographing the solar chromosphere, prominences and faculæ by monochromatic light.

4. A stellar spectrograph, for researches on the spectra and motions of stars, nebulæ, comets and planets.

5. A photoheliograph of great focal length, for photographing the direct solar image on a large scale.

The construction of the main building of the Observatory was begun in April 1895. After many delays, it is now under roof, and will be completed in the summer of 1896. Its form is that of a Roman cross, with three domes and a meridian room at the extremities. The principal axis of the building (about 330 feet long) lies east and west, with the dome for the 40-inch telescope at the western end. This dome, which will soon be erected by Messrs. Warner & Swasey, is 90 feet in diameter, allowing ample space for the tube of the great telescope, which, with its attachments, is about 75 feet long. The elevating floor of the observing room is 75 feet in diameter, and will be movable through a range of 22 feet, by means of electric motors.

Of the two smaller domes, the one to the northwest will contain the 12-inch telescope now at the Kenwood Observatory, and the other a 24-inch reflector. Between these domes is the heliostat room, 100 feet long and 12 feet wide. A heliostat with 24-inch plane mirror will stand on a pier at the north end of the room, under an iron roof which can be rolled away to the south.

The meridian room has double sheet-iron walls, with an intervening air space. It is designed to contain a meridian circle of large aperture, but for the present a transit instrument will suffice for the purposes of the Observatory.

The body of the building is divided through the center by a hallway extending from the meridian room to the great tower. On either side are offices and computing rooms, a library, lecture room, two spectroscopic laboratories, dark room, developing room, galvanometer room, chemical laboratory, instrument rooms, etc. In the basement is a large photographic dark room, an enlarging room, concave grating room with large concave grating spectroscope, emulsion room, constant-temperature room, physical laboratory and optician's room. The engines, dynamos and boilers for supplying power and heat are to be at a distance of several hundred feet from the Observatory.

OPTICAL LABORATORY AND INSTRUMENT SHOP.

One novel feature in connection with the Observatory will be its instrument shop and optical laboratory, where it is hoped that it will ultimately be possible to construct the greater part of the instruments and laboratory apparatus which will be needed for purposes of investigation. This work is undertaken not because of any lack of instrument makers in this country, but because it is believed that the best results can only be secured when instruments of research are constructed under the immediate supervision of those who are to use them. Desirable changes in construction or design which become evident as the work progresses can, under these circumstances, be more readily and inexpensively made than when the work is being done at a distance. In the end the instrument makers themselves cannot fail to benefit by the experiments thus undertaken and the types of apparatus evolved. Mr. G. Willis Ritchey has been placed in charge of the optical work. His equipment will consist of a large laboratory fitted with grinding and polishing apparatus, with complete arrangements for testing optical surfaces. The instrument shop, which will be used by Messrs.

Kandler and Gaertner, under the direction of Professor Wadsworth, will be equipped with a complete outfit of instrument-makers' tools.

SITE.

The Observatory is situated about a mile from the town of Williams Bay, near Lake Geneva, Wisconsin, in an ideal rural region, free from the dust and smoke of cities, and removed from the tremors of railroad traffic. Lake Geneva is about seventy-five miles from Chicago, and is reached by a branch of the Northwestern railroad. The site of the Observatory includes about fifty acres of wooded land fronting on the lake. It is believed that the conditions will be favorable for the most delicate investigations in all branches of astronomy and astrophysics.

PUBLICATIONS.

The publications of the Observatory will include: *Bulletins of the Yerkes Observatory*, containing announcements of results, brief descriptions of new buildings and instruments, and notes on the work of the Observatory; *Contributions from the Yerkes Observatory*, consisting of papers contributed to various astronomical and astrophysical journals and the proceedings of scientific societies; *Annals of the Yerkes Observatory*, in the form of quarto volumes containing detailed accounts of special researches; and the *Astrophysical Journal*, an International Review of Spectroscopy and Astronomical Physics, edited by Professor George E. Hale, Director of the Yerkes Observatory, and Professor James E. Keeler, Director of the Allegheny Observatory, with the coöperation of a board of assistant and associate editors.

LIBRARY AND MUSEUM.

It is intended to establish at the Yerkes Observatory a museum for the preservation and exhibition of photographs, charts and drawings of the Sun, Moon, planets, comets, meteors, stars and nebulæ and their spectra, and of optical phenomena observed in the laboratory; photographs and drawings of astronomical and physical instruments; and portraits of astronomers, astrophysicists and physicists.

Scientific men, learned societies and directors of laboratories and observatories are earnestly requested to assist in the formation of a library for the Observatory by contributing to it copies of their publications. Photographs of scientific subjects, on glass or paper, will be very wel-

come for exhibition in the museum. Drawings and catalogues of scientific instruments are also desired. It is expected that the Observatory will ultimately be able to make some return for such contributions in the form of its own publications and photographic results.

For the present, and until notice of removal to Lake Geneva has been published, packages intended for the Yerkes Observatory should be addressed to the *Kenwood Observatory, Chicago, U. S. A.* Large parcels may be sent through the agency of the International Bureau of Exchanges of the Smithsonian Institution, to which the Yerkes Observatory is already indebted for such service.

ACKNOWLEDGMENTS.

The present opportunity is taken to extend the cordial thanks of the Observatory to all who have favored it with gifts. Among those calling for special mention are the following:

The large and valuable collection of astronomical photographs exhibited by the Royal Astronomical Society at the Columbian Exposition in 1893; presented by the Society.

A collection of fifty positives on glass, from Professor Barnard's remarkable negatives of the Milky Way, nebulæ and comets; presented by Professor E. E. Barnard.

Eighty-seven bound volumes of astronomical and meteorological observations, including a complete set of the *Memorie della Società degli Spettroscopisti Italiani;* presented by Professor P. Tacchini.

Sixty-eight bound quarto volumes, including *Greenwich Observations* and *Photographic and Spectroscopic Results;* presented by W. H. M. Christie, Esq., Astronomer Royal.

Twenty-two bound quarto volumes of *Cambridge Observations;* presented by Sir Robert S. Ball, Lowndean Professor at Cambridge.

Thirty-nine quarto volumes of the *Annals of Harvard College Observatory;* presented by Professor E. C. Pickering, Director.

On the completion of the Yerkes Observatory the instruments of the Kenwood Observatory will be removed to Lake Geneva, and the existence of the latter institution will cease. To all who have enriched its library by contributions of their publications, grateful thanks are extended.

GEORGE E. HALE.

CHICAGO, February 10, 1896.

ON A NEW METHOD OF PREPARING PLATES SENSITIVE TO THE ULTRA-VIOLET RAYS.[1]

IT frequently happens that for various experimental purposes plates with a sensitive surface of pure silver bromide, or bromo-iodide, are required and are not always easy to prepare. Some few years ago Herr V. Schumann reported that he had found a means of preparing plates sensitive to the ultra-violet rays in regions hitherto quite unrecorded by photography. The full details of Herr Schumann's method of preparing these plates have how appeared in the Transactions of the Vienna Academy of Sciences, and present so many points of interest and show such thorough working out by Herr Schumann that a translation of the paper seemed desirable. It was intended originally to be merely an abstract for my own use, but it was found very difficult to condense it without loss. The paper forms the sequel of two papers on the "Photography of the Rays of Shortest Wave-Length," published in the same volume of the *Sitzungsberichte* (pages 415–475 and 625–694), which deal with the instruments and the necessary optical and electrical arrangements for taking these photographs of the region of the spectrum between $\lambda 2313.5$ and $\lambda 1000$, and the many difficulties to be surmounted in doing so, especially in the case of the wave-lengths between $\lambda 1820$ and $\lambda 1000$, for which entirely special arrangements had to be adopted.—J. W.

INTRODUCTION.

In my previous papers (noted above) I have followed out the spectrum of electric discharges far beyond the hitherto known limits of the ultra-violet ($\lambda 1852$), up to the neighborhood of wave-length 1000. The observations were carried out by photographic methods as far as $\lambda 1820$, with gelatino-bromide plates, and thence to $\lambda 1000$, with a plate which I prepared specially for this purpose by a new method.

The rays beyond $\lambda 1820$ have remained quite inactive by any method of spectroscopic observation hitherto employed. They are only perceptible with the above-mentioned plates, with lenses and prisms of fluor spar, and with the spectroscopic apparatus in a vacuum.

The method of preparation of these plates is the result of a research not yet finished, which I only notice briefly in the first part of the

[1] Translated from the *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften*, Math.-Naturwiss. Classe. Band CII., Heft. VIII., Wien, October 1893, pp. 994–1024. Communicated by COL. J. WATERHOUSE.

papers mentioned. It yields a coating for the plates of the desired fineness and sensitiveness, films which are more sensitive for the new rays than for the remaining part of the spectrum, and which, on this account, as I shall show later on, fulfil their purpose in two ways.

The plates are less satisfactory in other respects: they suffer in time from large and small defects in the surface, which can only be checked by proper exposure and by skillful application of definite precautionary measures for the development of the image. But as soon as this precaution is put aside numberless spots appear of different intensity and size, which overrun the image and destroy its otherwise remarkable sharpness. This is the direction in which my process requires improvement, and is, at the same time, the principal reason why I have not published it earlier. I certainly hope still to be able to overcome this defect, as a result of further researches, if more time is available to me for them, as my earlier observations lead me to believe this to be possible.

Under such circumstances it might have happened that the free publication of my process, which I had not intended until this improvement had been made, would have been indefinitely postponed, but this would not have agreed with the final object of my investigations, which was to make the spectroscopy of the new region of rays accessible as soon as possible.

The following circumstances have also influenced me: The above mentioned account of my researches on the shortest wavelengths has met with such a friendly reception that a more active interest in the investigation of the new region of rays seems to have already been secured. This is shown especially by the efforts that are being directed to the problem of extending our knowledge of the molecular theory by means of the spectrum. It may be remarked thereon, that the earlier researches in this direction, which first of all only aimed at the discovery of a regular connection between the lines of an element and between the spectra of different elements have, up to the present time, given the most favorable results the nearer they have approached the hitherto known boundaries of the ultra-violet region. The shorter the wave-lengths of the region under observation were, so much the more markedly this regularity was disclosed. From this it may be expected that the new region of rays, with its incomparably shorter wave-lengths, will yield rich material for observation towards the completion, as well as for the verification of the results

hitherto obtained ; and so much the more that the investigation of a whole series of elements, which has hitherto been quite without result in the direction mentioned, is directed on this part of the spectrum alone. For observations of this kind the new plates, even before their improvement, should be a welcome help. It is this especially which has, in the first place, decided me to abandon my original intention and publish my process at once.

The following paper treats of my own personal labors. These include a series of researches which, in consequence of the not inconsiderable difficulties which were caused at first by the necessity for taking these pictures of the spectrum in a vacuum, have occasioned great expenditure of time and trouble. I have therefore contented myself with single trials of the respective experiments in cases where the verifying of the first results seemed to me superfluous. These results are naturally of inferior value, and it might, perhaps, have been better if I had passed them over in silence. My paper would then have been so incomplete that their admission into it seemed to me to be the lesser of two evils. I shall, however, suitably note them in what follows, so that the possibly doubtful worth of one or the other of them may not influence the principal results of the investigation.

SPECTROGRAPHIC PREPARATORY WORK.

The spectrum in the ultra-violet was already known as far as $\lambda 1852$. In 1890 I succeeded in discovering waves of shorter length as far as $\lambda 1820$ by means of photography. Beyond this the photographic plates failed ; whether from want of sensitiveness or from the insufficient energy of the source of light, nothing further could be determined. The only possibility of obtaining an elucidation of this point lay in the measurement of the transparency to light of the different components of the sensitive coating of the plates. I used for this purpose gelatine dry plates containing gelatine and silver bromide.

Dry gelatine, as I was the first to show,[1] absorbs the ultra-violet rays very powerfully, and the more so in proportion to their refrangibility. A film only $0^{mm}.00004$ thick is sufficient to weaken very sensibly rays of about $\lambda 1852$.

The coating of a gelatine dry plate is at least 500 times thicker. Consequently, waves of shorter length have not the power of penetrating the sensitive depths of such a film, nor of reducing a sufficient quan-

[1] See vol. cii. part 2, 1893, pp. 457–464.

tity of silver haloid to give a dense image. From this it may be concluded that the gelatine was not without a share in the loss of intensity of my pictures of the spectrum, and that a film of pure silver bromide might have given a better effect.

Pure silver bromide also stops the rays of light energetically; however, according to my photographs, it is rather more transparent for the wave-lengths 2100 to 1850 than for the rest of the spectrum. This slight difference was practically of little importance. Of much more importance was the extent of the extinction which might result photo-chemically or photo-thermically. The absorption spectrum failed to elucidate this point. The photographic behavior of pure silver bromide could alone decide it.

With this object I coated a glass plate with a thin film of silver bromide, which had been precipitated with an excess of alkaline bromide, dried it, and with it took a photograph of the spectrum of the spark between two aluminium wires, using a quartz prism and lenses. The plate was developed like a gelatine dry plate, with pyrogallic acid, soda and potassium bromide. The thickly fogged plate showed a continuous spectrum which extended as far as λ 1820, in undiminished intensity, as a deep black band of action, bordered all round by a light edge. The continuity of this band was entirely owing to the spreading of all the lines together, an appearance which also occurs with gelatine plates of much higher sensitiveness.

From this negative I concluded that the modification of silver bromide in gelatine emulsion is not wanting in any way in sensitiveness for the most refrangible rays, nor these in photo-chemical energy, but rather that the want of sensitiveness of silver bromide in gelatine was a consequence of the weakening of the rays which these suffer on their passage to the silver bromide through the gelatine. Hence, it was to be expected that the sensitiveness of silver bromide plates could be increased by diminishing the quantity of gelatine, by substituting some more transparent binding medium for the gelatine, or, finally, by doing away with the binding material. This would only answer for the selected region of observation which ends with λ 1820. I therefore repeated these experiments for the more strongly refracted region lying near, taking care, however, to reduce the air-space between the source of light and the plate, which I had already previously recognized as an important absorbent for short waves of light, to a layer of only a few millimeters thickness. In this way it was proved that a

region rich in rays existed beyond λ 1820, and also that for photographing this pure silver bromide is sufficiently sensitive.

These photographs on pure silver bromide form the basis for the preparation of my plates sensitive to the ultra-violet rays, which is treated in the following section of this paper.

PREPARATION OF PLATES SENSITIVE TO THE ULTRA-VIOLET RAYS.

This was tried in three ways: by coating with emulsion, by bathing in silver nitrate and potassium bromide solutions, and by coating with precipitated silver bromide.

A. By Coating with Emulsions.—My endeavors to obtain an ultra-violet sensitive plate with emulsions of silver bromide have given no practical results. They are mentioned only for the sake of completeness.

I hoped, with a silver bromide emulsion containing two to three times as much silver bromide as usual, to obtain a coating poor in gelatine which would have allowed the rays to penetrate to a greater depth and given a more intense picture than is possible with ordinary silver bromide in gelatine. I obtained, however, the exact reverse of this. The silver bromide settled regularly at the bottom, even before the poured out emulsion was set, so that the uppermost surface of the coating of the plate, which in this case is alone of service, consisted merely of gelatine. Plates of this kind were, from the reasons already explained, more insensitive for the most refrangible rays than ordinary dry plates.

An attempt to replace gelatine by agar-agar was still more unsuccessful: the coating of the plate separated, as soon as it was set, into particles of varying sizes, an appearance which had already, some years before, prevented me from using agar-agar for emulsion purposes.

B. By Immersion in Silver Nitrate and Potassium Bromide Solutions.—If a plate coated with gelatine is dipped in a solution of silver nitrate and then in a solution of potassium bromide, a coating of silver bromide is obtained, of which the outer surface is formed of silver bromide without any gelatine. When such a plate is exposed to light the rays first pass through the silver bromide free from gelatine, and then through that which is enclosed in gelatine. From this film of silver bromide free of gelatine, I anticipated good results in photographing the smallest wave-lengths.

I coated a leveled glass plate with a 3 per cent. solution of gelatine, and, as soon as the coating was set, immersed it in a 5 per cent. solution of silver nitrate, let it drain, cleaned back and sides with blotting-paper, then immersed it again in the dark room in a 3 per cent. solution of potassium bromide and washed it, the coated side being downwards and the water changed constantly. After drying it was exposed to the spectrum of aluminium, and then developed with pyro-soda and potassium bromide.

The dried opalescent unexposed plates were found to be unevenly transparent, and showed numerous irregular streaks. They fogged completely on development, and could only be kept clear by strongly diluting the developer. However, the lines were in all cases sharply shown, even when the plate fogged, and more intense than with a silver bromide emulsion. The photographic maximum of the plate exposed to aluminium light was about the two lines at λ 1860 and λ 1852. Both always developed much earlier than the other parts of the spectrum.

Gelatine emulsion plates behaved just the opposite, these lines always appearing last.

Gelatine bath plates consequently have an advantage over emulsion plates for photographing the most refrangible rays.

These photographs ended at λ 1852. The cause of this moderate range must be sought, however, not in the plate, but rather much more in the fact that its exposure was under the influence of an air-space intervening in the path of the rays, and this, as before shown, is very slightly transparent to the ultra-violet rays.

The general sensitiveness of the gelatine bath plates was only moderate, and to have increased it, as was desirable, would have been difficult. I therefore contented myself with a single trial of this method, and without exposing plates to the wave-lengths beyond λ 1852, passed on to the last of the methods given, which, in other respects also, promised better results.

C. By coating with precipitated Silver Bromide.—If solutions of silver nitrate and potassium bromide are mixed, a flocculent precipitate of silver bromide is obtained. Very dilute solutions behave otherwise. They give, with an excess of potassium bromide, an extremely fine precipitate which first remains suspended and only settles after standing for weeks.

The addition of a few drops of ammonia increases the deposit, and hastens the settling.

If a glass plate be laid at the bottom of the settling vessel, the silver bromide falls on it in a layer of even thickness, and after the supernatant fluid has been syphoned off, dries in a short time to a dull yellowish coating, consisting of pure silver bromide with a small mixture of the salts dissolved in the supernatant fluid (KNO_3 and KBr), which can be removed by washing. Such plates stand development, and also, to a certain extent, the fixing, without injury.

The above is a rough outline of the method I have used for years for preparing plates which have enabled me to find the limits of the spectrum between wave-lengths 1820 and 1000.

V. SCHUMANN.

(To be continued.)

PROFESSOR MASCARI'S OBSERVATIONS OF VENUS.

THE three drawings reproduced in the accompanying plate were made by Professor Mascari of the Astrophysical Observatory of Catania, who has given much attention to the observation of Venus at Catania as well as at the Observatory on Mount Etna (altitude 2942^m). The drawing of 1892, October 13, was made under the best observing conditions, when the markings were exceptionally well defined. The dark line in the southern hemisphere, of broken and irregular form, was remarkably sharp, and the gray patches were clearly seen, though in the northern hemisphere they were somewhat diffuse. The observation of 1892, October 12, was made under less favorable conditions, and the image was unsteady. In that of 1895, December 11, the dark patches were distinguishable with difficulty, but their appearance was such as to leave no doubt of their reality. On December 14, at $11^h\ 25^m$ civil time, the same dark patches seen at 5^h A.M., December 11, were observed with certainty. In all of these observations, each occupying nearly two hours, the aspect of the planet was the same. It is evident that if the rotation period were 24^h a decided displacement of the dark markings must take place within an interval of 2^h. No such change was noticed, nor could any be detected in observations made before conjunction. It therefore seems to follow that the 24^h period should be rejected in favor of the long period of Schiaparelli. Observations recently made at Rome by Professor Tacchini also confirm Schiaparelli's conclusions.

PLATE XVIII.

FIG. 1.

October 12, 1892
$5^h\ 25^m$ to $6^h\ 32^m$ Catania C. T.

FIG. 2.

October 13, 1892
$5^h\ 54^m$ to $7^h\ 9^m$ Catania C. T.

FIG. 3.

December 11, 1895
5^h to $7^h\ 5^m$ Catania C. T.

DRAWINGS OF VENUS BY PROFESSOR A. MASCARI.

THE SHORT PERIOD VARIABLE δ CEPHEI.

In the November number of The Astrophysical Journal Mr. Alexander W. Roberts, of Lovedale, South Africa, writing upon "Close Binary Systems and their Relation to Short Period Variations," after, in the first instance, "accepting with confidence" M. Bélopolsky's elements, save one, that of inclination, 90°, obtained for the variable δ Cephei (presumably those contained in the February number of The Astrophysical Journal, p. 160, translated from *A. N.* 3257, and which are deduced from 34 spectrograms), and then, later on, suggesting a speculative alteration of Bélopolsky's epoch of minimum brightness so as to harmonize with his own induced theory advanced in this article, suggests a condition for the system of δ Cephei comprising two bright stars, a primary of 5.0 mag. possessing great heat-dispensing power which the companion star, between 7 and 8 mag., is capable of absorbing on its approach and arrival at periastron, its lustre thereby being increased to nearly 5.0 mag., while the pair would then yield a combined light equal to 4.2 mag., leaving over 0.5 mag. of its maximum brightness still unaccounted for. Now this theory, or some modification thereof, might possibly be advanced to explain the constant variations of this star, had the result of M. Bélopolsky's spectrographic investigations been arrived at by an observed alternate separation and closing up of two sets of lines, as in the case of a system consisting of bright components, and not, as it actually was in the case of δ Cephei, by an observed swinging to and fro of a single set of lines revealed by the aid of plates impressed with the spectra of iron and hydrogen. The interpretation of these investigations, I understood, was that the star circulated around a dark body, hence a *cool* or comparatively cool body, and one therefore incapable of increasing the brilliancy of its luminous companion, either by adding to its temperature or combining with its light as required by the Roberts theory. In this star, according to Bélopolsky, minimum preceded the cessation of spectroscopic recession in the line of sight by one day, so that an eclipse interpretation is not possible. Might not, however, tidal disturbances and *bodily* tides in the bright member excited upon its closer approach to the ruling dark body at and near periastron, explain the star's rapid rise in brilliancy, and its periodic variability? This tidal disturbance would not attain its maximum effect until some time after the luminous member had made its nearest approach to the disturbing body. May not also the great eccentricity of this and most

other stellar orbits be attributed to the effect of tidal friction ? Perhaps Dr. T. J. J. See, the eminent author of that brilliant paper on "Evolution of the Double Star Systems," read before the Chicago Academy of Sciences, February 7, 1893, and published in *Astronomy and Astro-Physics,* April 1893, may be willing to formulate a theory that will harmonize strictly with all the elements deduced from these, or that may be deduced from any later spectrograms that have been secured by M. Bélopolsky or other skillful observers, whether of δ Cephei or of any of the other members of this class of short period variables.

L. A. EDDIE.

GRAHAMSTOWN, CAPE COLONY,
December 28, 1895.

Reviews.

On the Photographic Spectrum of the Great Nebula in Orion. J. Norman Lockyer. *Phil. Trans.* **186,** A, 73–91, 1895.

Although a great amount of work has already been done by spectroscopists on the Orion nebula, many — in fact, most — of the important problems relating to it remain unsolved. In this paper Professor Lockyer, continuing the attack, gives the results of his photographic investigations of the spectrum, and discusses their bearing on the hypothesis of stellar development of which he is the chief advocate. The photographs were all made prior to 1890, and various preliminary notices of the results have already been published.

The instruments employed were a thirty-inch reflector, and a spectroscope with one prism of 60° and two half-prisms of 30°. No further data are given, and in this connection it becomes necessary to refer once more to the old question of the conditions of efficiency in spectroscopes which is brought up by Professor Lockyer, who seems to regard it as an open one, and refers to some passages apparently supporting his own views. It is hardly necessary to say that expressions of individual opinion have no weight in matters that are governed purely by physical laws.[1] The conditions of efficiency of spectroscopes have been very thoroughly worked out in earlier numbers of this Journal.[2]

As for Professor Lockyer's apparatus, we are assured that its dimensions were such that all the light falling on the spectroscope slit was transmitted to the photographic plate. So far this is well; but still other information is required before we can form a fairly correct estimate of the capabilities of the instrument. Whoever has had occasion to consult the older spectroscopic literature, either for purposes of criticism or for his own instruction, must have noticed that the really important data concerning the apparatus are almost always missing; they must be inferred from the results, which thus lose much of

[1] To prevent misunderstanding it may be well to point out that the remarks by Professor Campbell which are referred to apply only to the intensity of the images of bright lines on the photographic plate; the linear separation of the images is left out of consideration, the question being merely one of recording faint lines.

[2] See particularly the article by Professor Wadsworth, *Ap. J.* **1**, 52, 1895.

their value as a guide to further investigation. At the present time such omissions should not occur. The single statement which conveys the most information about an instrument is that of the resolving power, but since resolving power can be obtained in different ways, which practically are not quite equivalent, particularly when photographic methods are used, it is greatly to be desired that all future accounts of spectroscopic investigations should contain the following data: (1) the focal length and aperture of the large telescope; (2) the focal length and aperture of the collimator; (3) the dimensions, kind and number of prisms; (4) the focal length and aperture of the camera, or in the case of visual observations, the aperture and magnifying power of the observing telescope. Some of these data would be superfluous if spectroscopes were always properly constructed, but an examination of old instruments, and even of some comparatively modern ones, shows that this is by no means the case. Moreover, if an instrument is properly constructed there is no harm in giving the reader data by which he may assure himself of the fact.

Judging by results, Professor Lockyer's apparatus was at least well adapted to the recording of faint bright lines. The table of fifty-four lines in the spectrum of the Orion nebula is the most extensive that has been published, and its value is not affected by any conclusions that may be based on it. The wave-lengths, however, are rather rough approximations, as one would expect from the method by which they were determined and from the evidently small scale of the photographs. Many of the lines in the table can now easily be identified with the lines of helium, the complete spectrum of which has become known since the memoir was written, and a comparison with Runge's wave-lengths shows that the wave-lengths in the table are frequently in error by two, and occasionally by three-tenth meters. A much higher degree of accuracy than this is required for the certain identification of single unknown lines.

Notwithstanding the existence of these errors, the wave-lengths of all except the brighter lines in the table are more accurate than the best values available seven or eight years ago, and as a result of this narrowing of the limits of uncertainty, origins of the lines which were then considered probable by Mr. Lockyer are now excluded. It is interesting to note how greatly the part has shrunk which lines of the ordinary metals were supposed to play in the production of nebular spectra. Thus, instead of seven lines due to common elements (carbon,

magnesium, manganese, iron and lead) out of sixteen recorded nebular lines (three of which are due to hydrogen)[1], we now have only six out of the whole list of fifty-four, for which a similar origin is claimed. Of these six, one is the "magnesium" line at λ 5007; another is the calcium line which is practically coincident with *Hε*, and the existence of which is evidently inferred from the presence of a very faint line at λ 3933 (K?). The remaining four lines are excessively faint, and, in fact, are found only in this table. It is pretty evident that, leaving hydrogen and helium out of consideration, little progress has been made in determining the origin of lines in nebular spectra.

No origin is assigned to the strong line at λ 373, although its connection with the magnesium-flame triplet near the same place is regarded as an open question, to be settled by observations with higher dispersion. Such observations have, however, been made by others. There is no evidence in favor of the supposition that the line is due to magnesium.

In view of recent developments, the helium origin of this line at once suggests itself, but examination shows that it also is not supported by the facts. The wave-lengths which different observers have assigned to the line are as follows: Huggins, 3726; Campbell, 3727; Keeler, 3727; Lockyer, 3729. The nearest helium pair is at λ 3733.01. Lockyer has a nebular line at λ 3707, and there is a helium pair at λ 3705.15; but the nebular line is much fainter than the one at λ 373, while the relative brightness of the helium lines is just the reverse of this.

In the discussion of results the relations existing between the spectrum of the nebula and the spectra of neighboring stars are considered at length. The same subject has been investigated by other observers, and all results agree in demonstrating the closeness of the connection. Other spectral relations, such as those existing between planetary nebulæ and bright-line stars, are also considered with reference to their bearing on the meteoritic hypothesis, and one of the main points of the paper is to show that the relationship indicated between the planetary nebulæ and bright-line stars also holds good for such a nebula as that of Orion. The conclusions would call for more extended notice were it not that they confirm the views which the author had held on the basis of less elaborate investigations, and which are already well known. A figure, illustrating the transition from nebulæ to stars of the highest temperature, according to these views, is given on p. 88.

[1] *Meteoritic Hypothesis*, p. 290.

Some special features of the observations are to be mentioned. The conclusion that the fainter lines do not have the same brightness relatively to the hydrogen lines in different parts of the nebula agrees with the work of other observers. Dark absorption lines are found in the spectra of the trapezium stars. In the same spectra bright knots occur at the points of intersection with the nebular lines. Taken in connection with the absorption lines just mentioned, this appearance, if due to other than instrumental and photographic causes, would lead to the conclusion, which was rejected by Professor Campbell and the reviewer on the evidence of similar photographs,[1] that the nebular lines in the star spectra are doubly reversed. A distortion of the lines λ 4471 and λ 4495 on one of the plates (illustrated by a figure) would, if real, indicate a motion of 200 miles per second in the line of sight; the possibility that the bending of the lines may be due to a distortion of the film is, however, admitted, and it becomes a very strong probability when we observe that one of these lines belongs to helium, and and that the other helium lines are not affected.

A highly interesting feature of the same photograph is the indication of a reversal of the chief nebular line at λ 5007 in the spectrum of the star Bond 685. It is imperfectly represented in the figure. Unfortunately, the spectrum of this star is shown on only one plate. No reversal of the chief line in the spectrum of Bond 685 could be detected in 1893 by Professor Campbell or the reviewer. J. E. K.

SPECTROSCOPY OF BINARY SYSTEMS.

In recent numbers of the *Astronomische Nachrichten* have appeared, two articles by Dr. T. J. J. See, entitled "Theory of the determination, by means of a single spectroscopic observation, of the absolute dimensions masses and parallaxes of stellar systems whose orbits are known from micrometrical measurement; together with a rigorous method for testing the universality of the law of gravitation" (**139**, 17–26), and "On the theoretical possibility of determining the distances of star clusters and of the Milky Way, and of investigating the structure of the heavens by actual measurement" (**139**, 161–164).

The fundamental principle involved in the proposed method—namely, that when the apparent orbit of a binary system is known, but

[1] *A. and A.* **13**, 394, and 493, 1894.

one linear element is required in order to fix its absolute dimensions, and its parallax—is not new, having been suggested by Fox Talbot in 1871, and since variously applied, directly or inversely, by Niven, Rambaut, Wilsing, and Lehmann-Filhés.

The sight-line component of the orbital velocity is the desired linear element, and this can be accurately determined when the brightness of one of the component stars is sufficient to permit an application of the spectrographic method.

In developing the requisite geometrical formulæ, Dr. See employs the principle of the hodograph, and he gives (perhaps unnecessarily) two proofs of the well-known theorem that the hodograph of the ellipse is a circle whose radius is the quotient of the mass of the attracting body at the focus and the double areal velocity.

The radius-vector (ρ) of the point in the hodograph corresponding to a given point and velocity in the orbit is given by the formula

$$\rho = \frac{\kappa}{\sin \omega \sin i},$$

κ being the linear sight-line component, i being the inclination of the orbit-plane, and ω being the angle between ρ and the ascending node, equal to the angle made by the tangent to the orbit with the line of nodes, and determinate from the anomaly v, and the elements of the apparent orbit.

The radius (a) of the hodograph, which gives its scale, is obtained from the formula $a = \dfrac{\rho}{e \cos \phi \pm \sqrt{1 - e^2 \sin^2 \phi}}$ ϕ being the angle between the tangent and the parameter of the ellipse, and equalling $\frac{v}{2} + \frac{\gamma}{2}$, where $\sin \gamma = \dfrac{r \sin v}{2a - r}$ and γ is the "anomaly-angle" at the empty focus. The absolute value of the semi-major axis a is found by the formula

$$a = \frac{2 \bar{\rho} (t_2 - t_1)}{(r_1 + r_2) \sin (v_2 - v_1)}$$

where t_1 and t_2 are two epochs separated by some convenient interval of time, as a year, "when the companion is near apastron, and the velocity changes slowly," with their corresponding anomalies (v_1, v_2) and radii-vectores (r_1, r_2) and $\bar{\rho}$ is the average velocity (km. per sec.) in the interval, obtained from the hodograph.

The mass of the system in terms of that of the Sun and Earth is found, as usual, on the assumption of the validity of the law of gravi-

tation, by Kepler's harmonic law, and the distance of the system is determined in the usual manner, $\Delta = \frac{a}{\sin a''}$.

The law of gravitation may be tested by the comparison of subsequent spectroscopic observations with the values of κ deduced from the absolute elements of the orbit.

For a dozen binaries with well determined orbits, Dr. See has computed for 1896.5 the velocity in the orbit (ρ) in units of the radius (a) of the hodograph, with the fractional part of this velocity $\left(\frac{\kappa}{\rho}\right)$ which is in the line of sight. For five of these stars, η Cassiopeiae, 9 Argus, α Centauri, Σ 2173, and β Delphini, the conditions are particularly favorable for the determination of κ, on account of its large relative amount, $\frac{\kappa}{\rho}$ being near to unity. For α Centauri and 70 Ophiuchi, the trigonometrically known parallaxes indicate that the sight-line component should amount respectively to 7 and 11^{km} per sec., quantities surely within the range of spectrographic accuracy, provided only that the brightness of the stars is sufficient. Equivalent statistics were given for 1891.0 by Rambaut for forty-five orbits (*M. N.* **50**, 307–310, 1890).

Of course the present limitation of all these geometrical applications of the general principle stated by Talbot lies in the insufficiency of our present optical means, or the lack of sensitiveness of our photographic plates. Thus far the sight-line velocity has been spectrographically determined for less than sixty stars. Yet it seems probable that the velocity of at least the brighter component of some of these binaries ought to be within the reach of our largest instruments, and it is to be hoped that the measurement may be undertaken with some of the great refractors already equipped with spectrographs.

Dr. See's second article applies the results of the first to find the distance of star clusters and the Milky Way, on the assumption that binary systems discovered within clusters or the Milky Way are really members of those groups. Common proper motion, magnitude, and spectral type (not a necessary condition) with the stars surrounding the binary would increase the presumption of a common distance, but the results obtained would, of course, be unreliable to the extent of the inaccuracy of the assumption. Even if not at present available, the suggestion may at some time be useful. E. B. F.

The Sun. New and revised edition. CHARLES A. YOUNG. (International Scientific Series. Vol. XXXIV. D. Appleton & Co., New York, 1895.)

The success with which researches in solar physics have been prosecuted since 1881, when this well-known work first appeared, has been recognized in the various subsequent editions by the addition of numerous notes and appendices. The present edition, however, represents a most thorough revision of the text, and the addition of much new matter and many illustrations. In fact, a careful comparison of the text with that of the 1884 edition shows that we are dealing with what is almost a new work, retaining all the excellent qualities which have rendered its predecessor so justly popular, with the added interest of new observational and theoretical results, described without prejudice, and estimated at their true value. Though written for the general reader, to whom it has proved most acceptable, it is safe to say that the book is kept within reach by every astronomer. To illustrate how fully the revised edition represents the present state of our knowledge of the Sun, it will perhaps be profitable to enumerate the principal changes and additions which it embodies. These epitomize the progress of solar research during the last eleven years.

The general remarks which form the introduction to the volume called for no important modifications and remain substantially as they were originally. The value of the solar parallax, with which chapter i. is principally concerned, has undergone no very marked change during the last decade, and the approximate result $8''.80$ given in the earlier edition, is retained. (The values adopted by Newcomb and Harkness in their recent volumes of astronomical constants are $8''.797 \pm 0.004$ and $8''.809 \pm 0.006$ respectively.) The principal additions to this chapter are an account of the observations of the transit of Venus in 1882, with a cut of the photoheliograph, and a brief description of Gill and Elkins' determination of the solar parallax from heliometric observations of the minor planets. Chapter iii. has been considerably enlarged; it now contains a description of Rowland's gratings, with a cut of the ordinary form of mounting for concave gratings; remarks on spectrum photography and its value for certain classes of work; an excellent cut of the great Princeton spectrograph attached to the 23-inch telescope; descriptions of the spectrum maps of Rowland, Higgs and Langley; Rowland's latest list of the elements present in the reversing layer;

Trowbridge's results with regard to oxygen in the Sun, showing that none of the bright lines in the line spectrum of oxygen occur in the solar spectrum between $\lambda\,3750$ and $\lambda\,5034$; the spectroscopic investigations of Crew and Dunér on the solar rotation; and Cornu's method of picking out the telluric lines by causing them to vibrate in unison with an oscillating solar image. (It may be noted in passing that the references on p. 64, line 14, should be to pages 74 and 202.)

The chapter on "Sun-spots and the Solar Surface" describes the work of Deslandres and Hale,[1] in photographing the solar surface with the spectroheliograph; corrects the popular belief in a sudden and decided magnetic disturbance precisely coinciding in time with Carrington's unique observation of a brilliant object moving across a Sun-spot; and includes Professor Young's own observations of the bulbous ends of penumbral filaments seen in Sun-spots. His success in resolving the ends of the filaments into fine, sharp-pointed hooks with the 23-inch Princeton refractor, seems to indicate that their ordinary appearance is due to poor "seeing" and insufficient resolving power. A cut of the great Sun-spot of October 1883, from a drawing by Tacchini, appears on p. 128. A discussion of the observations of Howlett and Sidgreaves, whose results oppose those of Wilson and De La Rue, does not lead the author to abandon the long-established idea that spots are depressions in the photosphere. While the painstaking researches of the later investigators are entitled to most respectful consideration, and must be taken into account in all future discussions of the subject, it is probable

[1] One passage here, which entirely misrepresents my views, cannot be allowed to pass without correction. It reads as follows: "This makes it more or less probable that the faculæ, instead of being mere protrusions from the photosphere, are really luminous masses of calcium vapor floating in the solar atmosphere,—possibly as Professor Hale thinks, identical with the prominences themselves. But Deslandres and Maunder dissent from this, and say that while these objects shown by the spectroscope are clearly connected with the prominences, they are as clearly not identical with them." As a matter of fact, I have always considered the combined evidence to indicate that the brighter reversed regions represent the hot calcium vapor, rising from the Sun's interior through the faculæ, and distributed throughout their upper portion. In certain exceptional cases, to some of which I have called attention, bright eruptive prominences on the disk may be photographed. M. Deslandres now holds that the spectroheliograph shows the calcium vapor in the chromosphere above the faculae, but not in the faculæ themselves. The question at issue is simply this: At what height above the photosphere do the bright reversals originate? M. Deslandres' earlier view was as follows: "Cependant les flammes faculaires sont formées de calcium et d'hydrogène; elles ont le même composition que les protubérances; ce sont des protubérances se projetant sur le disque."—*Knowledge*, December 1893.

that to the majority of solar physicists the balance of evidence seems to lie on the side of the older view. The common lack of symmetry in Sun-spots, and the rapidity with which they develop while crossing the disk, render statistical studies of penumbral width somewhat inconclusive, as the conflicting evidence clearly testifies. Although observations of spots at the limb are ordinarily complicated by the presence of an encircling ring of faculæ, they may be said to favor, rather than to oppose, the original idea of Wilson. It may be that micrometrical measures of the apparent width of the penumbra may ultimately assist in deciding the matter.

The period of the Sun's axial rotation deduced by Hornstein, Bigelow and Veeder from periodic variations in the Earth's magnetism are given in a new footnote "for what they are worth," the author evidently wishing to see them much more firmly established than they are at present, before incorporating them in the text. The discussion of the important subject of the equatorial acceleration is somewhat augmented, and now includes Wilsing's period deduced from measures of the faculæ recorded on the Potsdam photographs. The fact that these results do not agree with observations of spots and Dunér's spectroscopic measures in establishing a general equatorial acceleration has never been satisfactorily explained, though the necessity of determining the positions of the faculæ from plates which show them only when near the limb, naturally lessens one's confidence in Wilsing's conclusions. The changes in form which ensue during the passage of a facula across the disk are such as to make subsequent identification of the point previously measured practically impossible. Bélopolsky's results (which are not given by Professor Young) appear to him to contradict those of Wilsing, and to give periods corresponding with those of the spots. Wilsing rightly maintains that no very certain inferences can be drawn from the limited number of measures made by Bélopolsky, and concludes from a discussion of the observations that they merely show a constant difference from his own. Bélopolsky replies that they refer to a much higher latitude, and the constant difference pointed out is in very close agreement with the corresponding difference between the rotation periods of spots in the respective zones. Moreover, as Professor Young remarks, Stratanoff's more recent results are in substantial accordance with Carrington's spot period. The question demands a much more extended investigation than it has hitherto received. Other additions to this chapter include a reference to Bélopolsky's application

to the Sun of Jukowsky's investigations on the rotation of fluid masses, a cut representing the apparent positions of the solar axis at different times of the year, and a correction to the previous edition regarding Spoerer's views as to the condition of the Sun's interior.

Chapter v., dealing with the periodicity of Sun-spots, their effects upon the Earth, and theories as to their cause and nature, has naturally received much attention in the revision. Wolf's Sun-spot numbers are brought down to 1891. It is fortunate that the continuity of the series, broken by the death of Professor Wolf in 1893, has been restored by his successor, Herr Wolfer. Spoerer's important discovery of the variation of spots in latitude during the eleven-year period is described, and illustrated by curves showing the distribution of the spots in latitude from 1855 to 1880. Dr. Veeder's idea that auroras are the direct result of disturbances at the eastern limb of the Sun does not commend itself to Professor Young, who quotes Maunder's statement that in a period of nearly nineteen years the three greatest magnetic storms have been simultaneous with the maximum development of the three greatest Sun-spots, none of which were near the eastern limb at the time. That in certain cases violent disturbances on the Sun's limb exactly coincide with twitches of the magnetic needle is illustrated by Professor Young's well-known observation of this kind at Mount Sherman in 1872. But equally violent phenomena with no corresponding magnetic perturbations have been far more frequently observed. Our author does not consider the Sun's effect upon terrestrial magnetism to be a direct one—the passage he quotes from Lord Kelvin's 1892 address seems to disprove that; but he does hold that there is a connection of some kind between solar activity and the oscillations of the magnetic needle. In the case of a magnetic storm he considers it not impossible that the Sun expends sufficient energy to "pull the trigger," but not necessarily to produce the explosion. Whence comes the energy represented by the storm itself remains an apparently insoluble mystery.

Wilson's recent measures of the heat radiated from Sun-spots are referred to in connection with those of Langley, and attention is called to the interesting fact that the radiation of the umbra as compared with that of the neighboring photosphere increases as the limb is approached. Among the recent theories of spot formation those of Lockyer, Schaeberle and Oppolzer are given in outline. The two former are in practical agreement with that of Sir John Herschel, in so far as they attribute the genesis of a spot to the fall of heavy masses upon

the photosphere,—an idea which can hardly be reconciled with the statements of Secchi, Sidgreaves and others that faculæ sometimes appear upon the disk before the spot has formed. Oppolzer's theory is more favorably criticised, but the difficulty of accounting for the polar streams is pointed out, and it might have been added that as yet we have no substantial observational evidence of their existence.

In passing on to a discussion of the prominences no important changes are introduced until the list of chromospheric lines is reached. In this the lines λ7065.50 and *f* are now ascribed to helium, while H and K, which in the earlier addition were doubtfully credited to hydrogen, are now given to calcium. A woodcut, after an excellent photograph by Professor Reed of the C line doubly reversed in the chromosphere spectrum, is given on p. 209, Trouvelots "dark" prominences and Tacchini's "white" prominences are mentioned in the discussion of the ordinary types, but with the remark "that the evidence hardly warrants confident belief in the existence of such objects." Brester's theory of a quiescent solar atmosphere, with prominence forms produced by the effects of luminescence, is criticised on the ground that it offers no adequate explanation for the line distortions ordinarily attributed to motion in the line of sight. Until it is proved that a flash lighting up a succession of stationary particles can produce the spectroscopic phenomena observed in eruptive prominences, Brester's theory cannot be expected to receive favorable consideration from solar physicists. Schmidt's theory has gained rather wider acceptance, but a closer examination of its consequences is leading some of its former supporters to abandon it, at least in its application to the Sun. Among the numerous objections which have been raised against it, that pointed out by Professor Young is as simple and conclusive as any. A mass of metallic vapors exposed to the cold of space must inevitably form a photosphere within a short time. Permanent gases would not thus condense, and it may therefore be that some of the planetary nebulæ conform to Schmidt's theory.

The remainder of the chapter is devoted to an account of the methods and results of prominence photography, a field in which Professor Young himself was the first to experiment. (On p. 230, line 22, "1884" should be "1889".) The cuts include excellent double reversals of H, K and $H\epsilon$, and prominences photographed in the H, K and $H\alpha$ lines through a wide slit at Princeton; the spectroheliograph used from 1891 to 1895 at the Kenwood Observatory, and three groups of prominences

photographed with it. The work of Deslandres and Hale is accurately described, though the spectroheliograph used by the former is much more efficient than that with which he is credited.

Chapter vii. is enriched with three new cuts of the corona, from photographs taken at the eclipses of 1882, 1889 and 1893. (In the title of Fig. 91, "Burckhardt" should be "Burckhalter.") Unfortunately the beautiful detail of Professor Schaeberle's photograph of the inner corona has been lost in the process of reproduction. An account of the unsuccessful attempts of Huggins, Wright and Hale to photograph the corona without an eclipse closes with the assurance that "to the writer at least, the case appears by no means hopeless"—a crumb of comfort that those who are still engaged upon the problem can hardly fail to appreciate. The five pages devoted to theories of the corona include those of Hastings, Schaeberle and Bigelow, with a brief description of the suggestive electrical experiments of Pupin.

The first half of the next chapter, on the Sun's light and heat, remains practically unchanged, and is followed by a revised account of Langley's bolometric work, with cuts of the spectrobolometer and a small map of the infra-red spectrum. The results of Langley, Frost and Wilson, on the radiation of the photosphere at various distances from the center of the disk, are tabulated for convenient comparison. Taken in connection with the earlier photometric measures of Pickering and Vogel, they agree in bringing out very clearly the rapid increase of absorption in the upper spectrum. In the discussion of the effective temperature of the Sun, Rosetti's value of 10000°C. is now supplemented by Le Chatelier's and Wilson and Gray's results of 7600°C. and 8000°C. respectively. Scheiner's conclusion, derived from a study of the relative intensities of two magnesium lines, that the temperature of the reversing layer at the altitude where the magnesium absorption is produced is about equal to that of the electric arc, is also given.

The volume closes with a valuable summary of the observatory and laboratory investigations of helium.

The present review, touching as it does upon only its new features, must fail to convey any sense of the continuity of an exceptionally well-constructed work. Professor Young's well-known clearness of expression and attractive style will recommend the book to every intelligent reader.

G. E. H.

Observations des Protubérances Solaires faites à l'Observatoire d'Odessa. A. KONONOWITSCH, N. ZWIETINOWITSCH, A. ORBINSKIJ. (Odessa, 1895).

The observations contained in this volume were undertaken in 1892 at the suggestion of M. Bredichin, through whose influence a direct vision spectroscope with two prisms was provided for the 6½-inch refractor of the Odessa Observatory. The tabulated results, which cover the period August 1892—August 1893, include (1) Odessa civil time of observation; (2) position angle of center of prominence; (3) length of base in degrees of the solar circumference; (4) height in seconds of arc. Prominences whose spectra contained lines other than the first three of the hydrogen series and D_3 are specially designated. It would appear, however, that attention was confined almost exclusively to observations in the $H\alpha$ line, as in examining other parts of the spectrum the adjustment of the slit in the focal plane of the telescope was left at the position for this line. It is evident that under such circumstances other lines would be seen only at a great disadvantage. The length of prominences along the limb was measured with a filar micrometer, which served also to determine the height of those near the poles. The height of prominences in lower latitudes was deduced from the time of transit across the (tangential) slit. The volume contains a complete series of scale drawings of all prominences seen, the daily observations being platted in parallel strips, showing the solar circumference with the prominences at the measured position angles. No attempt is made to show the structure of the chromosphere. Considering the differences in the instruments employed, and in the times of observation, the drawings show a fairly good agreement with those published in the *Memorie della Società degli Spettroscopisti Italiani.*

G. E. H.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of THE ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

CHRISTIE, W. H. M. Mean areas and heliographic latitudes of Sun-spots in the year 1893, deduced from photographs taken at Greenwich, Dehra Dûn (India) and in Mauritius. M. N. **56,** 11–14, 1895.

GUILLAUME, J. Observations du Soleil, faites à l'observatoire de Lyon, pendant le troisième trimestre de 1895. C. R. **121,** 1120–1122, 1895.

FÉNYI, J. Considérations sur la nature des protubérances solaires. C. R. **122,** 72–73, 1896.

FÉNYI, J. Nouvelle interprétation du phénomène des protubérances solaires. C. R. **121,** 931–933, 1895.

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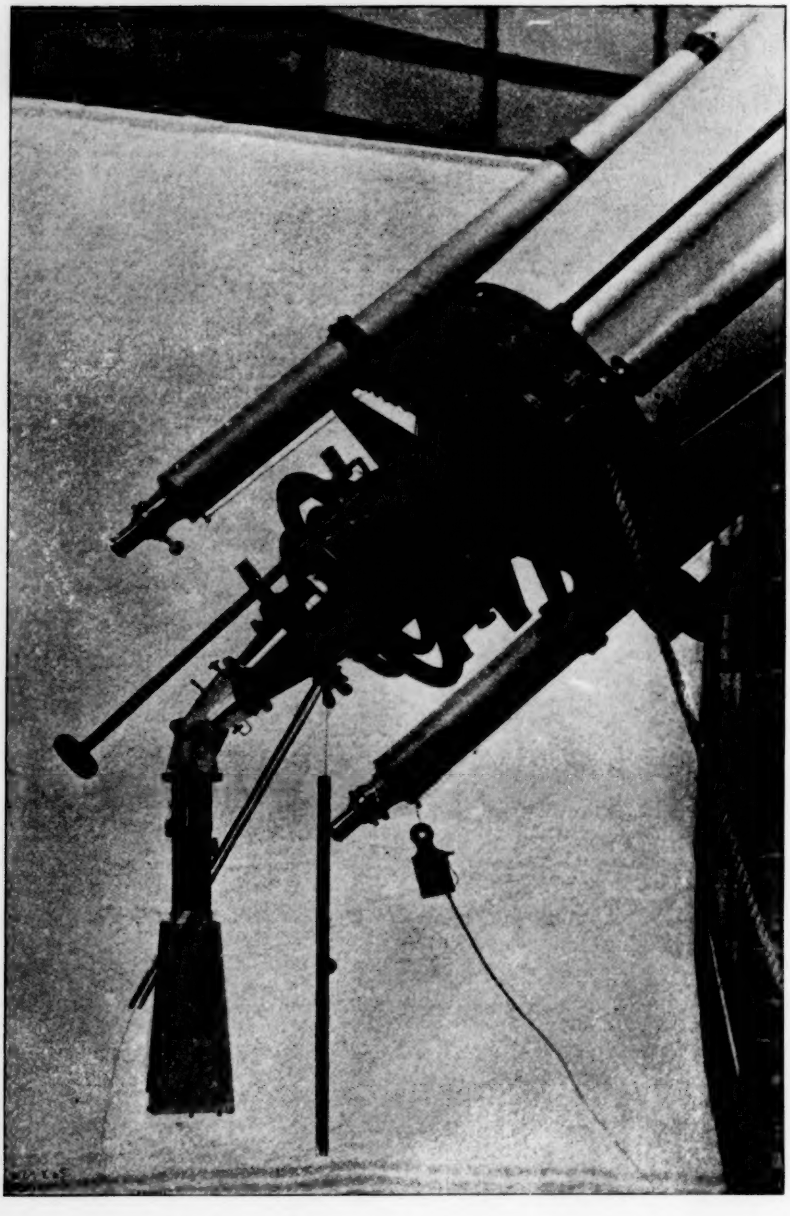

THE EYE-END OF THE NEWALL TELESCOPE WITH THE SPECTROSCOPE ATTACHED.